AD~755 408

ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

Q. L. Deel, et al

Battelle Columbus Laboratories

Prepared for:

Air Force Materials Laboratory

September 1972

DISTRIBUTED BY:



U. S. DEPARTMENT OF COMMERCE 5285 Port Royal Road, Springfield Va. 22151

AFML-TR-72-196 VOLUME II

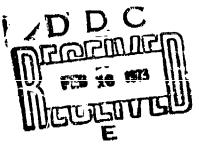
ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

O. L. DEEL and H. MINDLIN

Buttelle Columbus Laboratories

TECHNICAL REPORT AFM1-TR-72-196
VOLUME II

SEPTEMBER 1972



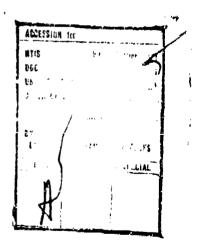
Approved for public release; distribution unlimited

Rep-oduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield VA 22151

Air Force Systems Command Wright-Patterson Air Force Base, Ohio

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the covernment may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or well any patented invention that may in any way be related thereto.



Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

Security Classification BOXUMENT CONTROL DATA - RAD (Bossetly standification of title, body of aburest and indonting anatistian must be entered when the averall report to alreadiled) 1. ORIGINATING ACTIVITY (Corporate outhor) 24. REPORT SECURITY CLASS FICATION Battelle Unclassified Columbus Leboratories 2 6 6 ROUP 505 King Avenue, Columbus, Ohio 43201 NĄ S. REPORT TITLE Engineering Data on New Aerospace Structural Materials 4. DESCRIPTIVE NOTES (Type of report and highestre drive) Final Summary Report, April 1971 to July 3372 S. AUTHOR(S) (Last name, Hest name, Initial) Deel, O. L., and Mindlin, H. TAL TOTAL NO. OF PASES 6. PEPORT DATE 75. NO. OF REFS 168 September 1972 A GRICHATOR'S REPORT NUMBER(S) SE. CONTRACT OR SHANT NO. F33615~71~C-1261 AFML-TR-72-196 Vol. II 7381 \$4. OTHER REPORT NO(8) (Any other numbers that may be assigned Task No. 736106 10. AVAILABILITY/LIMITATION NOTICES Approved for public release; distribution unlimited 12. SPONSORING MILITARY ACTIVITY 11. SUPPLEMENTARY NOTES Air Force Materials Laboratory Wright-Fatterson Air Force Base, Ohio 13. ABSTRACT The major objectives of this research program were to evaluate newly developed materials of interest to the Air Force for potential weapons system usage, and then to provide "data sheet" type presentation of engineering data for these materials. The effort covered in this report has concentrated on 15-5 PH (H1025) forged bar, HP 9N1-4Co-0.20C forged bar, PH 13-8 Mo (H1060) forged bar, 7049-T76 extrusions, Ti-6A1-2Sn-4Zr-6Mo sheet, Income1 702 sheet (Aged), and Incomel 706 forged bar (creep-rupture heat trea ment). The properties investigated include tension, compression, shear, bend, impact, fracture toughness, fatigue, creep and stress rupture, and stresscorrosion at selected temperatures.

Ta

.50M. 1473

Security Classification

MEN DURKE		LINK A				<u> </u>										# B	LINK C	
KEY WORDS	ROLE	<u> </u>	ROLE	WT	ROLE													
Mechanical Properties																		
Chemical Composition	ĺ																	
Corrosion Resistance																		
Physical Properties																		
Stainless Steel																		
Alloy Steel		Ì																
Aluminum Alloy																		
Nickel Base Alloy			Ì															
Titanium Alloy		Ì	}															
15-5 РН																		
PH 13-8 Mo	-																	
9N1-4Co-0.20C	1				Į.													
7049	}]		ì	İ												
Ti-6-2-4-6	l																	
Inconel 702]					ĺ												
Inconel 706						Ì												
	1		ļ		ļ	1												
	Ì																	
						Ì												
				1														
	1					ł												
	1			1														
	! !																	
					}													
			1]	1													
					1													
			i															
	Ì				i													
	1		ĺ															
					1													
]																	
			1															
	!																	

I6

Security Classification

ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

O. L. Deel and H. Mindlin

Approved for public release; distribution unlimited.

FOREWORD

This report was prepared by Battelle's Columbus Liboratories, Columbus, Onio, under Contract F33615-71-7-1261. This contract was performed under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Clayton Harmsworth (AFML/LAE), technical manager.

This final report covers work conducted from April, 1971, to July, 1972. This report was submitted by the authors on August 4, 1972.

This technical report has been reviewed and is approved.

a. Oberten

A. Olevitch

Chief, Materials Engineering Branch Materials Support Division Air Force Materials Laboratory

TABLE OF CONTENTS

																Page
INTRODUCTION																1
MATERIALS INFORMATION AND TEST RESU	LTS									•					•	3
15-5 PH Stainless Steel	, .															3
Material Description																3
Processing and Heat Treat																3
Test Results																5
HP 9Ni-4Co-0.20C Alloy Steel				_		_		_	_			_	_			21
Material Description			•		_					-						21
Processing and Heat Treat	ine		-		-	-	_		_		-	_	Ì			21
Test Results																21
PH 13-8 Mo Stainless Steel .																41
Material Description																41
Processing and Heat Treat	_															41
Test Results	• •	• •	•	•	•	•	•	•	•	•	٠	•	•	•	٠	41
7049-T76 Aluminum Extrusions						_		_		_	_	_				60
Material Description																60
Processing and Heat Treat																60
Test Results	. T.(18	• •	•	٠	•	•	•	•	•	•	•	•	•	•	•	60
lest weedits , , .	• •	• •	•	•	•	٠	•	•	•	•	•	•	٠	•	•	00
Ti-6A1-2Sn-4Zr-6Ho Alloy			•			•									•	78
Material Description				٠				•	•		•		٠		•	78
Processing and Heat Treat	ing	• •	,				•		•		•		•	• .	•	78
Test Results			•	٠	•	•	•	•	•	•	•	•	•	•	•	78
Inconel 702 Alloy																96
Material Description	• •	• •	•	•	•	•	•	•	•	•	•	•	•	•	•	96
Processing and Hope Treat	150	• •	•	•	•	•	•	•	•	•	•	•	•	•	•	96
Processing and Heat Treat Test Results	TILE	• •	•	′	•	•	•	•	•	•	•	•	•	•	•	96
lest Results	• •	• •	•	•	•	•	•	•	•	•	•	•	•	•	•	90
Inconel 706 Alloy																113
Material Description																113
Processing and Heat Treat																113
Test Results																113
DISCUSSION OF PROGRAM RESULTS	• 0			•	•	•	•	•	•	•	•	٠	•	٠	•	132
CONCLUSIONS		_							_						_	132
CONORDIGIONO	• •	• •	•	•	•	•	•	•	•	•	•	•	•	•	•	
APPE	ENDIX	7.														
EXPERIMENTAL PROCEDURE					_	_	,		_							135
	• •	•	·	Ť	Ī	•	-		•	•	-	Ť	-	-	-	
APPE	ZIDIX	11														
SPECIMEN DRAWINGS																143
APP	ENDIX	II	Ι													
DATA SHEETS																147
	-	-	-	-	-	•						-	·			
Preceding page blank	iv															

LIST OF TABLES

			Page
lable	I	Tensile Test Results for 15-5 PH (H1025) Forged Bar	6
	II	Compression Test Results for 15-5 PH (H1025) Forged Bar .	7
	III	Shear Test Results for 15-5 PH (H1025) Forged Bar	8
	IV	Impact Test Results for 15-5 PH (H1025) Forged Bar	9
	v	Fracture Toughness Test Results for 15-5 PH (H1025) Forged par (Longitudinal)	10
	VI	Axial Load Fatigue Test Results for Unnotched 15-5 PH (H1025) Forged Bar (Transverse)	11
	AII	Axial Load Fatigue Test Results for Notched $K_t = 3.0$) 15-5 PH (H1025) Forged Bar (Transverse)	12
	VIII	Summary Data on Creep and Rupture Properties of 15-5 PH (H1025) Forged Bar (Transverse)	13
	IX	Tensile Test Results for HP 9Ni-4Co-0.20C Forged Bar	24
	x	Compression Test Results for HP 9Ni-4Co-0.20C Forged Bar.	26
	λι	Shear Test Results for HF 9Ni-4Co-0.200 Forged Bar	28
	XII	Impact Test Results for HP 9Ni-4Co-0.20C Forged Bar	29
	MIII	Fracture Teighness Test Results for HP 9N1-4Co-0,20C Forged Bar	20
	XIV	Axial Load Fatigue Test Results for Unnotched h 9Ni-4Co-0.20C Forged Bar (Transverse)	31
	xv	Axial Load Fatigue Test Results for Notched (Kg = 3.0) HP 9Ni-4Co-0.20C Forged Bar (Transverse)	32
	XVI	Summary Data on Creep and Rupture Properties of HP 9Ni-4Co-0,20C Forged Bar (Transverse)	33
	xvii	Tensile Test Results for PH 13-8 Mo (H1000) Forged Bar .	44
	XVIII	Compression Test Results for PH 13-8 Mo (H1000) Forged Bar	45
	ХIX	Shear Test Results for PH 13-8 Mo (H1000) Forged Bar	47
	XX	Impact Test Results for PH 13-8 Mc (H1000) Forged Bar	48

ν

LIST OF TABLES (Cortinued)

			Ī	age
Table	XX1	Fracture Toughness Test Results for PH 13-8 Mo (H1000) Forged Ear (Longitudinal)		49
	XXII	Axial Load Fatigue Test Results for Unnotebed PH 13-8 Mo (H1000) Forged Bar (Longitudinal)		50
	XXIII	Axial Load Fatigue Test Results for Notched (K _c = 3.0) PH 13-8 Mo (H1000) Forged Bar (Longitudinal)		51
	XXIV	Summary Data on Creep and Rupture Properties of PH 13-8 Mo (H1000) Forged Bar (Longitudinal)		52
	vxv	Tensile Test Results for 7049-T76 Extrusions		63
	IVXX	Compression Test Results for 7049-T76 Extrusions		64
	XXVII	Shear Test Results for 7049-T76 Extrusions	•	6 5
	IIIVXX	Impact Test Results for 7049-T76 Extrusions at Room Temperature	•	66
	XX IX	Fracture Toughness Test Results for 7049-T76 Extrusions (Longitudinal)	,	67
	XXX	Axisl-Load Fatigue Test Results for Unnotched 7049-T76 Extrusions (Transverse)	•	68
	XXXI	Axial Load Fatigue Test Results for Notched (K = 3.0) 7049-176 Extrusions (Transverse)	-	69
	XXXII	Summary Data on Creep and Rupture Properties of 7049-T76 Aluminum Extrusions (Transverss)		70
	XXXIII	Tensile Test Results for Ti-6A1-2Sn-4Zr-6Mo Sheet	•	81
	XXXIV	Compression [est Results for Ti-£Al-2Sn-4Zr-6Mo Sheet .	-	83
	xxxv	Shear Test Results for T1-6A1-2Sn-42r-6Mo Sheet at Room Temperature		85
	XXXVI	Axial Load Fatigue Test Results for Unnotched Ti-6Al-2Sn-4Zr-6Mo Sheet (Transverse)	•	86
	IIVXXX	Axial-Load Fatigue Test Results for Notched (K = 3.0) Ti-6Al-2Sn-4Zr-6rio Sheet (Transverse)		87
	XXXVIII	Summary Data on Creep and Rupture Properties of		88

LIST OF TABLES (Continued)

			Page
Table	XXX IX	Tensile Test Results for Inconel 702 Sheet (Aged)	99
	X I.	Compression Test Results for Inconel 702 Sheet (Aged)	101
	XII	Shear Test Results for Inconel 702 Sheet (Aged)	102
	XLII	Axial Load Fatigue Test Results for Unnotched Inconel 702 Sheet (fged) (Transverse)	103
	XLIII	Axial Load Fatigue Test Results for Notched (Kt = 3.0) Inconel 702 Sheet (Aged) (Transverse)	104
	XLIV	Summary Data on Creep and Rupture Properties of Inconel 702 Sheet (Aged) (Transverse)	105
	XLV	Tensile Test Results for Inconel 706 Forged Bar (Stress-Rupture Heat Treatment)	116
	XTAI	Compression Test Results for Inconel 706 Forged Bar (Stress-Rupture Heat Treatment)	117
	XLVII	Shear Test Results for Inconel 706 Forged Bar (Stress-Rupture Heat Treatment)	119
	XLVIII	Impact Test Results for Inconel 706 Forged Bar (Stress-Rupture Heat Treatment)	120
	XLIX	Fracture Toughness Test Results for Inconel 706 Forged Bar (Stress-Rupture Heat Trestment)	121
	L	Axial Load Fatigue Test Results for Unnotched Incomel 706 Forged Bar (Stress-Rupture Heatment) (Transverse)	122
	LI	Axial Load Fatigue Test Results for Notched (K = 3.0) Inconel 706 Forged Bar (Stress-Rupture Leat Treatment) (Transverse)	123
	LII	Summary Data on Creep and Rupture Properties for Inconel 706 Forged Bar (Stress-Rupture Heat Treatment) (Transverse)	124
		LIST OF ILLUSTRATIONS	
F i gure	1	Specimen Layout for 15-5 PH (H1025) Forged Bar	4
	2	Typical Tensile Stress-Strain Curves for 15-5 PH (H1025) Forged Bar (Longitudinal)	14
	3	Typical Tensile Stress-Strain Curves for 15-5 Fli (H1025) Forged Bar (Transverse)	15

]	Page
Figure	4	Typical Compressive Stress-Strain and Tangent-Modulus Curves for 15-5 PH (H1025) Forged Bar (Longitudinal)		16
	5	Typical Compressive Stress-Strain and Tangent-Modulus Curves for 15-5 PH (H1025) Forged Bar (Transverse)		17
	6	Effect of Temperature on the Tensile Properties of 1.5-5 PH (H1025) Forged Bar		13
	7	Effect of Temperature on the Compressive Properties of 15-5 PH (H1025) Forged Bar		18
	8	Axial Load Fatigue Behavior for Unnotched 15-5 PH (H1025) Forged Bar		19
	9	Axial Load Fatigue Behavior for Notched (K _t = 3.0) 15-5 PH (H1025) Forged Bar	•	19
	10	Stress-Rupture and Plastic Deformation Curves for 15-5 PH (H1025) Forged Bar (Transverse)		20
	11	Specimen Layout for HP 9Ni-4Co-0.20C Forged Bar		22
	12	Typical Tensile Stress-Strain Curves for HP 9Ni-4Co-0.20C Forged Bar (Longitudinal)		34
	13	Typical Tensile Stress-Strain Curves for HP 9Ni-4Co-0.20C Forged Bar (Transverse)		35
	14	Typical Compressive Stress-Strain and Tangent-Modulus Curves for HP 9Ni-4Co-0.20C Forged Bar (Longitudinal)		36
	15	Typical Compressive Stress-Strain and Tangent-Modulus Curves for HP 9Ni-4Co-0.20C Forget Bar (Transverse)		37
	16	Effect of Temperature on the Tensile Properties of HP 9N1-4Co-0.20C Forged Bar		38
	17	Effect of Temperature on the Compressive Properties of HP 9Ni-4Co-0.20C Forged Bar		38
	18	Axial Load Fatigue Results for Unnotched HP 9N1-4Co-0.20C Forged Bar		39
	19	Axial Load Fatigue Results for Notched (K = 3.0) HP 9Ni-4Co-0.20C Forged Bar		39
	20	Stress-Rupture and Plastic Deformation Curves for HP 9Ni-4Co-0.20C Forged Bar (Transverse)		40

			Page
Figure	21	Specimen Layout for PH 13-8 Mo (E1000) Forged Bar	42
	22	Typical Tensile Stress-Strain Curves for PH 13-8 Mo (H1000) Forged Bar (Longitudinal)	53
	23	Typical Tensile Stress-Strain Curves for PN 13-8 Mo (H1000) Forged Bar (Long Transverse)	54
	24	Typical Compressive Stress-Strain and Tangent-Modulus Curves for PH 13-8 Mo (H1000) Forged Bar (Longitudinal)	55
	25	Typical Compressive Stress-Strain and Tangent-Modulus Curves for PH 13-8 Mo (H1000) Forged Bar (Long Transverse)	
	26	Effect of Temperature on the Tensile Properties of PH 13-8 Mo (H1000) Forged Bar	57
	27	Effect of Temperature on the Compressive Properties of PH 13-8 Mo (H1000) Forged Bar	57
	28	Axial Load Fatigue Results for Unnotched PH 13-8 Mo (HIGOO) Forged Bar	58
	29	Axial Load Fatigue Results for Notched (Kt = 3.0) PH 13-8 Mo (H1000) Forged Bar	58
	30	Stress-Rupture and Creep Deformation Curves for PH 13-8 Mo (H1003) Forged Bar (Longitudinal)	59
	31	Specimen Layout for 7049-176 Extrusions	61
	32	Typical Tensile Stress-Strain Curves for 7049-T76 Extrusions (Longitudinal)	71
	33	Typical Tensila Stress-Strain Curves for 7049-T76 Extrusions (Transversa)	. 72
	34	Typical Compressive Stress-Strain and Tangent-Modulus Curves for 7049-T76 Extrusion (Longitudinal)	. 73
	35	Typical Compressive Stress-Strain and Tangent-Modulus Curves for 7049-T76 Extrusion (Transverse)	, 74
	3 6	Effect of Temperature on the Tensile Properties of 7049-T76 Extrusion	, 75
	37	Effect of Temperature on the Compressive Properties of 7049-T76 Extrusion	. 75
	38	Axial Load Fatigue Results for Unnetched 7049-T76 Extrusions	s 76

			Page
Figures	39	Axial Load Facigue Results for Notched (K _t = 3.0) 7049-T76 Extrusions	76
	40	Stress-Rupture and Plastic Deformation Curves for 7049 Extrusions	77
	41	Specimen Layout for Ti-6A1-2Sn-4Zr-6Mo Sheet	79
	42	Typical Tensile Stress-Strain Curves for Ti-6Al-2Su-4Zr-6Mo Sheet (Longitudinal)	89
	43	Typical Tensile Stress-Strain Curves for Ti-6Al-2Sn-4Zr-6Mo Sheet (Transverse)	90
	44	Typical Compressive Stress-Strain and Tangent-Modulus Curves for Ti-6Al-2Sn-4Zx-6Mo Sheet (Longitudinal)	91
	45	Typical Compressive Stress-Strain and Tangent-Modulus Curves for Ti-6Al-2Sn-4Zr-6Mo Sheet (Transverse)	92
	46	Effect of Temperature on the Tensile Properties of Ti-6Al-2Sn-4Zr-6Mo Sheet	9 3
	47	Effect of Temperature on the Compressive Properties of Ti-6A1-2Sn-4Zr-6Mo Sheet	93
	48	Axial Load Fatigue Results for Unnotched Ti-6Al-2Sn-4Zr-6Mo Sheet	94
	49	Axial Load Fatigue Results for Notched (K = 3.0) Ti-6Al-2Sn-4Zr-6Mo Sheet	94
	50	Stress-Rupture and Plastic Deformation Curves for Ti-6Al-2Sn-4Zr-6Mo Sheet (Transverse)	95
	51	Specimen Layout for Inconel 702 Sheet	97
	52	Typical Tensile Stress-Strain Curves for Inconel 702 Sheet (Aged) (Longitudinal)	106
	53	Typical Tensile Stress-Strain Curves for Inconel 702 Sheet (Aged) (Transverse)	107
	54	Typical Compressive Stress-Strain and Mangent-Modulus Curves for Inconel 702 Sheet (Aged) (Longitudinal),	108
	55	Typical Compressive Stress-Strain and Tangent-Modulus Curves for Inconel 702 Sheet (Aged) (Transverse)	109

			Page
Figure	56	Effect of Temperature on the Tensile Properties of Inconel 702 Sheet (Aged)	110
	57	Effect of Temperature on the Compressive Properties of Incomel 702 Sheet (Aged)	110
	58	Axial Load Fatigue Results for Unnotched Incomel 702 Sheet (Aged)	111
	59	Axial Load Fatigue Results for Notched (K = 3.0) Inconel 702 Sheet (Aged)	111
	€0	Stress-Rupture and Plastic Deformation Curves for Inconel 702 Sheet (Aged) (Transverse)	112
	61	Specimen Layout for Inconel 706 Forged Bar	114
	62	Typical Tensile Stress-Strain Curves for Inconel 706 Forged Bar (Longitudinal) (Stress-Rupture Heat Ireatment) .	125
	63	Typical Tensile Stress-Strain Curves for Incomel 706 Forged Bar (Transverse) (Stress-Rupture Heat Treatment)	126
	64	Typical Compressive Stress-Strain and Tangent-Modulus Curves for Inconel 706 Forged Bar (Longitudinal) (Stress-Rupture Heat Trestment)	
	65	Typical Compressive Stress-Strain and Tangent-Modulus Curves for Inconel 706 Forged Bar (Transverse) (Stress- Rupture Heat Treatment)	128
	66	Effect of Temperature on the Tensile Properties of Incomel 706 Forged Bar (Stress-Rupture Heat Treatment)	129
	67	Effect of Temperature on the Compressive Properties of Inconel 706 Pouged Bar (Stress-Rupture Heat Treatment)	129
	68	Axial Load Fatigue Results for Unnotched Inconel 706 Forged Bar (Stress-Rupture Heat Treatment)	1.30
	69	Axial Load Fatigue Results for Notched (K = 3.0) Incomel 706 Forged Bar (Stress-Rupture Heat Treatment)	130
	70	Stress-Rupture and Plastic Deformation Curves for Incomel 706 Forged Bar (Stress-Rupture Heat Treatment) (Transverse).	131
	71	Tensile Ultimate Strength as a Function of Temperature	133
	72	Tensile Yield Strongth as a Function of Temperature	134

			Page
Figure	73	Sheet and Thin-Plate Tensile Specimen	144
	74	Round Tensile Specimen	144
	75	Sheet Compression Specimen	144
	76	Round Compression Specimen	144
	77	Sheet Creep- and Stress-Rupture Specimen	144
	78	Round Creep- and Stress-Rupture Specimen	144
	79	Sneet Shear Test Specimen	145
	80	Fin Shear Specimen	145
	81	Upnotched Sheet Fatigue Specimen	145
	82	Notched Sheet Fatigue Specimen	145
	83	Unnotched Round Fatigue Specimen	145
	84	Notched Round Fatigue Specimen	145
	85	Sheet Fracture Toughness Specimen	146
	8 6	Slow Bend Fracture Toughness Specimen	146
	87	Stress-Corrosion Specimen	146
	88	Thermal-Expansion Specimen	146
	(OO	fuctured Twhertovous phecomen	-
	89	Sheet Band Specimen	146
	90	Notched Impact Specimen	146

INTRODUCTION

The selection of structural materials to most effectively satisfy new environmental requirements and increased design load requirements for advanced Air Force weapons systems is of vital importance. A major difficulty that design engineers encounter, particularly for newly developed materials, materials processing, and product forms, is a lack of sufficient engineering data information to effectively evaluate the relative potential of these developments for a particular application.

In recognition of this need, the Air Force has sponsored several programs at Battelle's Columbus Laboratories to provide comparative engineering data for newly developed materials. The materials included in these evaluation programs were carefully selected to insure that they were either available or could become quickly available on request and that they would represent potentially attractive alloy projections for weapons system usage. The results of these programs have been published in four technical reports, AFML-TR-67-413, AFML-TR-68-211, AFML-TR-70-252, and AFML-TR-71-249.

This technical report is a result of the continuing effort to relieve the above situation and to stimulate interest in the use of newly developed alloys, or new processing techniques for older alloys, for advanced structures.

The materials evaluated under this program are as follows:

- (1) 15-5 PH (H1025) stainless steel forged bar
- (2) HP 9Ni-4Co-0.20C steel forged bar
- (3) PH 13-8 Mo (H1000) stainless steel forged bar
- (4) 7049-T76 aluminum extrusion
- (5) 6A1-2Sn-4Zr-6Mo titanium sheet
- (6) Inconel Alloy 702 sheet (Aged)
- (7) Incomel Alloy 706 forged bar (Creep-rupture heat treatment).

The temper or heat-treat conditions selected for evaluation are described in each alloy section.

The program approach was, as on previous contracts, to search the published literature and to contact metal producers and aerospace companies for any pertinent data. If very little pertinent information was available, a complete material evaluation was conducted. Upon completion of each material evaluation, a "data sheet" was issued to make the data immediately available to potential users rather than defer publication to the end of the contract term and the summary technical report. These data sheets are reproduced in Appendix III.

HARMATTA THE MANAGEN OF STATE OF

Detailed information concerning the properties of interest, test techniques, and specimen types are contained in Appendices I and II of this report.

MATERIALS INFOPMATION AND TEST RESULTS

15-5 PH Stainless Steel

Material Description

15-5 PH is a precipitation-hardening stainless steel that offers a combination of high strength and hardness, excellent corrosion resistance, plus good transverse toughness and good forgeability. It is produced by consumable vacuum arc remelting and is virtually "ferrite free".

Fabrication practices for 15-5 PH are generally the same as those established for 17-4 PH. Most techniques are similar to those recommended for the regular grades of stainless steel. Hardening heat treatments require temperatures of only 900 F to 1150 F, depending on the properties desired. Because of the comparatively low hardening temperatures, scaling and distortion difficulties are essentially eliminated.

15-5 PH is available in the form of sheet, strip, plate, bar, and wire. Typical applications include forgings, rump and valve parts for high pressure systems, aircraft components, and hollow bar parts for hydraulic actuators and controls.

The chemical composition of the forging used for this evaluation is as follows:

Chemical Composition	Percent
Carbon	.037
Manganese	,31
Phosphorus	.018
Sulfur	.010
Silicon	.30
Chromium	15.14
Nickel	4.58
Copper	3.32
Columbium	. 24
Tantalum	.01
Iron	Balance

The material tested was obtained from Armco Heat 4W0370 in the form of 2-1/8 inch x 5-3/4 inch x 8 foot forged bar.

Processing and Heat Treating

The specimen layout for 15-5 PH is shown in Figure 1. Specimens were machined in the as-received Condition A followed by heat treatment for 4 hours at 1025 F to Condition H1025.

- į
2
=
1
1
=
=
בֶּ
⊒•
114
61
71
C1
ET
I
65
49
99
68
151
_
41
5
51
1.8
65
15
91
23
-
16
67
97
E:
۰
12
6
4
2
81
<u> "</u>
6
45
3
┣-
15
6

2	3			
Frort Tough 64				
Frort				
6.3	67			
62 63	66 67			
		6	₽T	_
		2110	21.12	
5	2	213 219	17.2	
1112	OITS SITS	ž LG	20	
ers *	OITS	_	9	
TIS	MS TS	2	껄	
ers	9TS	212 213	2,5	
213	214	1	ارا	
17.8	212	Į į	2	_

FIGURE 1, SPECIMEN LAYOUT FOR 15-5 PH (H1025) FORGED BAR

Test Results

Tension. Results of tests in both the longitudinal and transverse directions at room temperature, 400 F, 700 F, and 900 F are given in Table I. Typical tensile stress-strain curves at temperature are shown in Figures 2 and 3. Effect-of-temperature curves are shown in Figure 6.

Compression. Results of tests in the longitudinal and transverse directions are given in Table II for room temperature, 400 F, 700 F, and 900 F. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 4 and 5. Effect-of-temperature curves are shown in Figure 7.

Shear. Results of pin shear tests in the longitudinal and transverse directions at room temperature are given in Table III.

Impact. Results of room temperature Charpy tests in the longitudinal and transverse direction are given in Table IV.

Fracture Toughness. Six slow-bend type tests were conducted at room temperature. Results are presented in Table V. Since the size ratio, $2.5(K_Q/TYS)^3$, was greater than both the specimen thickness and width in all tests, the K_Q value is not a valid K_{1C} value by existing ASTM criteria.

Fatigue. Axial-load tests were conducted at room temperature, 400 F, and 700 F for both unnotched and notched transverse specimens. Test results are given in Tables VI and VII and presented as S-N curves in Figures 8 and 9.

Crcep and Stress Rupture. Tests were performed at 700 F, 900 F, and 1100 F. Results are presented in tabular form in Table VIII and as log-stress versus log-time curves in Figure 10.

Stress Corrosion. Specimens were tested as described in the experimental procedure section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 6.7×10^{-6} in/in/F for 70 F to 900 F.

Density. The density value is 0.283 lb/in3.

TABLE 1. TENSILE TEST RESULTS FOR 15-5 PH (H1025) FORGED BAR

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Reduction in Area, percent	Tensile Modulus, psi x 10 ⁸
- Humber	Derengen, Kar	Strength, KSI	percent	percent	psi x 10
	Long	itud inal at Room	Temperature		
1L-1	164.0	163.0	15.0	62.4	30.5
1L-2	165.0	164.0	15.5	63.6	30.8
1L-3	164.0	163.0	15,5	62.2	30.6
	Trai	nsverse at Room '	[emperature		
1T-1	164.0	162.0	12,5	50.0	28.7
1T-2	165.0	162.0	13.0	52.7	28.6
1T-3	163.0	161.0	13.5	50.9	29.2
		Longitudinal a	t 400 F		
1L-4	147.0	141.0	12.5	50.0	27.3
1L-5	147.0	140.0	12.5	49.8	27.8
1L-6	147.0	140.0	11.5	48.8	28.1
		Transverse at	400 F		
1T-4	147.0	141.0	10.5	43.3	27.9
1T~5	146.0	139.0	10.5	42.0	27.2
1T-6	147.0	141.0	11,5	43.7	29.5
		Longitudinal a	t 700 F		
1L-7	137.0	128.0	10.0	43.5	26.5
1L-8	136.0	127.0	10.0	46.4	27.0
1L-9	139.0	130.0	11.0	46.2	27.4
		Transverse at	700 F		
1T-7	136.0	126.0	9.0	38.8	24.0
1T-8	136.0	128.0	9.0	37.8	25.2
1T-9	136.0	127.0	9.5	39.2	26.2
		Longitudinal a	t 900 F		
1L-10	120,0	112.0	15.0	60.8	21.9
1L-11	120.0	111.0	15.0	58,3	21.3
1L-12	119.0	110.0	14.0	58.2	23.4
		Transverse at	900 F		
1T-10	118.0	108.0	14.0	51.0	23.7
1T-11	118.0	110.0	13.5	50.2	23,0
1T -12	120.0	112.0	13.0	53.2	22.9

TABLE II. COMPRESSION TEST RESULTS FOR 15-5 PH (H1025) FORGED BAR

	0.2 Percent	Compressive
Specimen	Offset Yield	Modulus,
Number	Strength, ksi	psi x 10 ⁸
	Longitudinal at Room Temperature	
2L-1	168.0	29.8
2L-2	165.0	31.0
3 L-3	173.0	29.9
	Transverse at Room Temperature	
2T -1	165.0	29,8
2T-2	166.0	30.1
2T-3	165.0	30,9
	Longitudinal at 400 F	
2 L -4	145.0	29.1
2L-5	145.0	28.3
2L-6	144.0	28.9
	Transverse at 400 F	
2T -4	145.0	28.2
2T-5	143.0	29.3
2T-6	144.0	29.2
	Longitudinal at 700 F	
2L-7	133,0	27.9
2L-8	129.0	27.7
2L-9	128.0	27.4
	Transverse at 700 F	
2T-7	130.0	27.8
2T -8	130.0	28.6
2T -9	130.0	27.8
	Longitudinal at 900 F	
2L-10	113.0	24.6
2L-11	111.0	24.4
2L-12	111.0	24.2
•	Transverse at 900 F	
2T-10	111.0	25.3
2T -11	. 111.0	23.9
2T-12	111.0	24,2

TABLE III. SHEAR TEST RESULTS FOR 15-5 PH (H1025) FORGED BAR

Specimen Number		Ultimate Shear Strength, ksi
	Longitudinal	_
4L-1		106.0
4L-2		106.0
4L-3		105.0
4L-4		105.0
	Transverse	
4T-1		105.0
4T-2		104.0
4T-3		104.0
4T-4		106.0

TABLE IV. IMPACT TEST RESULTS FOR 15-5 PH (H1025) FORGED BAR

Specimen Number	Energy, ft/lbs
Longitu	dinal
10L-1	81.0
10L-2	81.0
10L-3	80.0
10L-4	78.0
10L-5	82.5
10L-6	81.5
Transv	rerse
10T-1	37.0
10T-2	38.5
10T-3	38.5
10T-4	43.0
10T-5	44.0
10T-6	43.0

TABLE V. FRACTURE TOUGHNESS TEST RESULTS FOR 15-5 PH (H1025) FORGED BAR (LONGITUDINAL)

Specimen Number	W, inches	a, inch	T, inch	P, pound	Span, inches	$f(\frac{a}{w})$	K _Q (a)
1L	1,501	.873	.749	11,800	6	3.5	181.49
4L	1.500	.886	.749	12,600	6	3,6	200.6
2L	1.500	.883	. 748	12,050	6 .	3.6	190.6
6Ľ	1.501	.891	.749	12,450	6	3,7	200.2
3L	1.500	.852	.748	11,900	6	3.3	174.5
5L	1.500	.882	.749	12,600	6	3.6	198.6

⁽a) Candidate fracture toughness values, K_Q , are invalid as $K_{\bar{1}c}$ values since a, T, <2.5 $\binom{K_Q}{\bar{1}\bar{1}\bar{1}\bar{5}\bar{5}}$.

TABLE VI. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED 15-5 PH (H1023) FORGED BAR (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Liferime, cycles
	Room Temperature	. The state of the
5- 5	170	18,720
5-3	165	42,200
5-2	160	120,700
5-4	155	111,200
5-1	159	4,156,200
5-6	14	275,300
5 ~7	140	7,934,500
5-8	135	
5-9	130	4,167,900 20,030,900
	400 F	
5-20	160	14,900
5-19	150	31,600
5-18	140	47,000
5-23	136	49,800
5-22	130	113,500
5-24	120	በላለ በበሰ
5-25	120	10,208,100
	700 🖫	
5-10	140	(b)
5-14	135	37,700
5-13	130	32,700
5-16	125	66,600
5-11	120	59,400
5-17	125	50,400,
5-12	110	10,123,000

⁽a) Did not fail.

⁽b) Failed in first cycle.

TABLE VII. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_E=3.0) 15-5 PH (H1025) FORGED BAR (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5 -31	130	9,260
5-32	120	14,650
5-33	110	16,010
5 - 34	90	45,120
5 -3 5	80	80,250
5-36	70	128,930
5-37	. 60	191,100
5-38	50	10,965,000
	400 F	
5-43	110	14,100
5-49	90	39,100
5-40	80	55,200
5-41	70	100,000
5 - 52	65	147,260
5-42	60	7,121,200
5-53	60	7,121,200 16,121,300 ^(a)
	700 F	
5-59	100	11,000
557	90	16,500
5-56	80	47,700
5 <i></i> 55	70	44,400
5 -60	70	815,200
5-53	65	2,547,900
5-54	60	5,548,760
5-61	55	17,060,300

⁽a) Did not fail.

TABLE VIII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES OF 15-5 PH (H1025) FORGED BAR (TRANSVERSE)

				Houre to	Hours to Indicated Creep	d Creep					
Specimen	Stress,	Temp,	1	De	Deformation, percent	•		Initial Strain,	Rupture Time,	Elongation in 2 in.	Minimum Creen Pate.
No.		£4,	0.1	0.2	6.5	1.0	2.0	percent	hr	percent	percent/hr
31	134.5	700	;	2	3	ı	ł	1	On loading	0 0	•
	130	=	0.01	0,03	0.35	2.0	12		37.3	10.8	0.08
. 33	125	r	0.10	4.0	7.0	30	86	0.857	410.9	12.3	0.013
	105	5	8.0	60	475(b)	1300(4)		0.539	312.5(4)	0.543	0.0006
	85	E	65	325	2225 ^(b)	ŀ	1	0.481	503.5 (a)	0.723	0.00015
310	100	906	;	0.7	0.5		1.0	0.750	1.6	13.8	1.7
314	85	=	0.15	0.65	6.3	36	68	0.450	139.7	11.5	0.013
34	70	=	7	22	280		705	0,338	861.6	36.1	0.0008
311	09	=	4.4	75	550,	<u> </u>	ł	0.385	578.6(4)	0.915	0,00063
313	20	:	20	350	(a) 096	ļ	i	0.265	772.4(8)	0.631	0.00027
36	20	100	0.05	6.17	0.75	1.9	3.7	0.267	9.9	23.0	0.44
35	ဗ္ဂ	=	1.0	4.5	20	51	8	0.357	167.5	38.5	0.015
37	20	=	3.2	17	92	217	370	0.150	725.4	32.3	0.0036
312	10	Ξ	9	180	680	1635(b)	1	0.077	671.8 ^(a)	0.573	0.00053

Test discontinued. Estimate. **3 3**

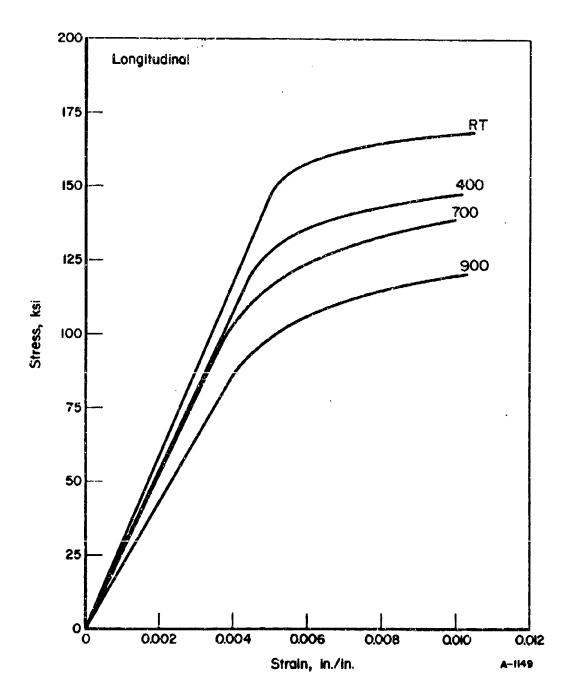


FIGURE 2. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 15-5 PH (H1025) FORGED BAR (LONGITUDINAL)

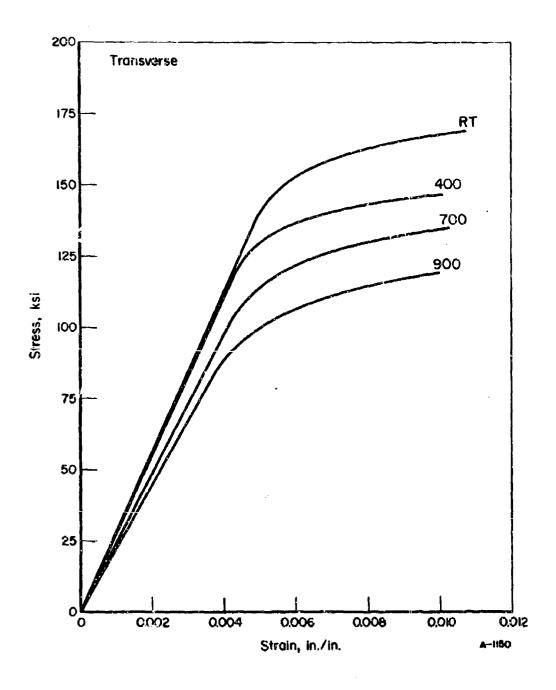


FIGURE 3, TYPICAL TENSILE STRESS-STRAIN CURVES FOR 15-5 PH (H1025) FORGED BAR (TRANSVERSE)

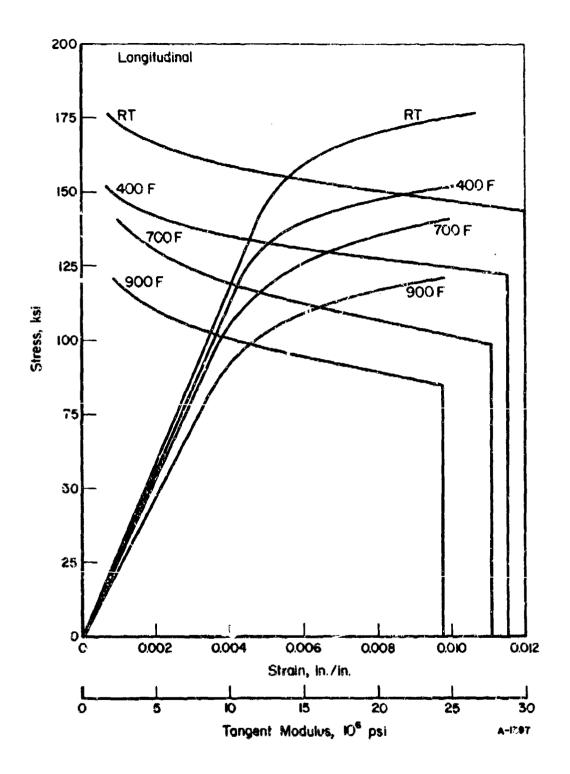


FIGURE 4. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR 15-5 PH (H1025) FORGED BAR (LONGITUDINAL)

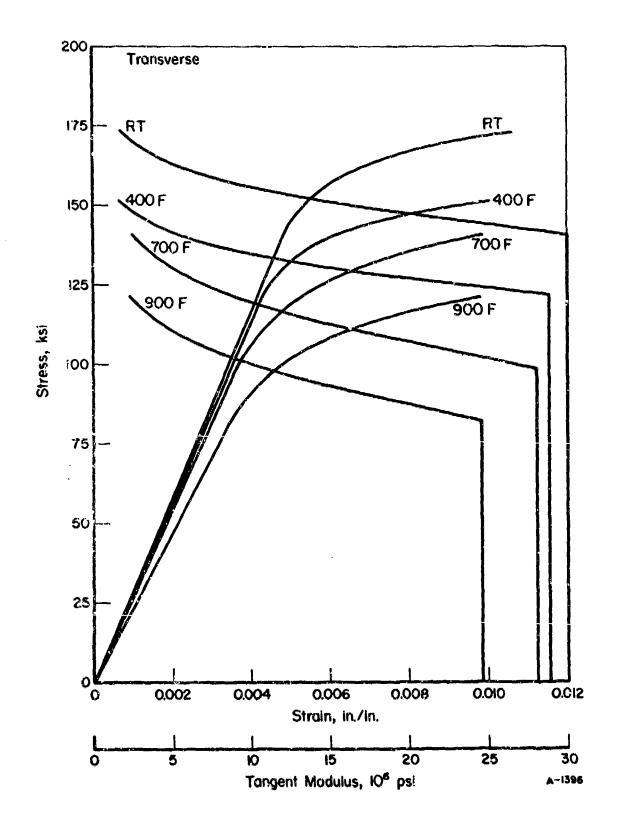


FIGURE 5. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR 15-5 PH (H1025) FORGED BAR (TRANSVERSE)

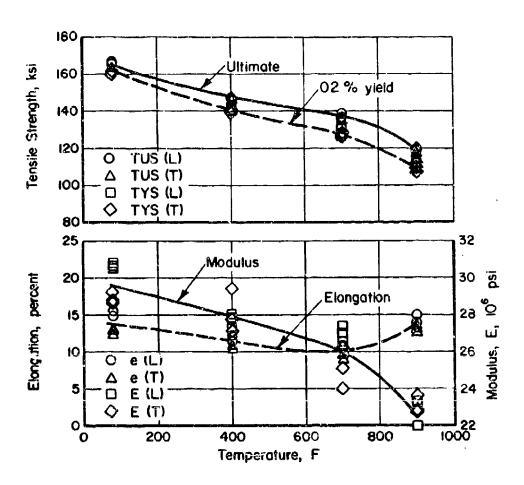


FIGURE 6. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 15-5 PH (H1025) FORGED BAR

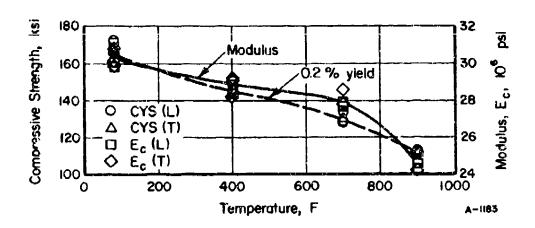


FIGURE 7. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 15-5 PH (H1025) FORGED BAR

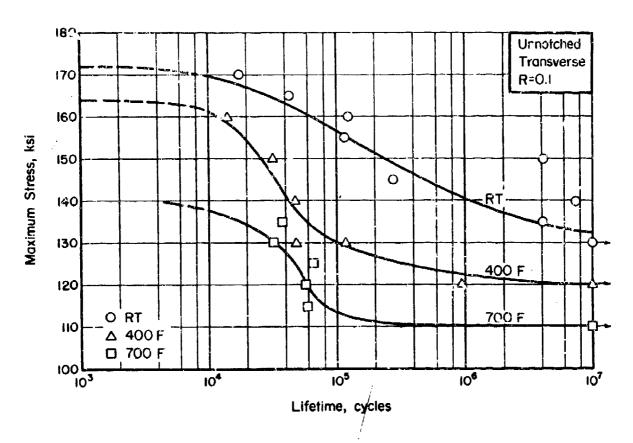


FIGURE 8. AXIAL LOAD FATIGUE BEHAVIOR FOR UNNOTCHED 15-5 PH (H1025) FORGED BAR

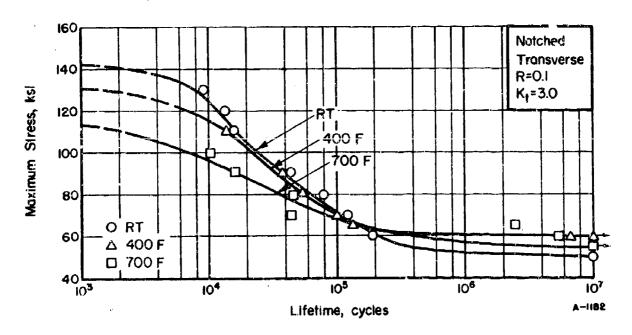
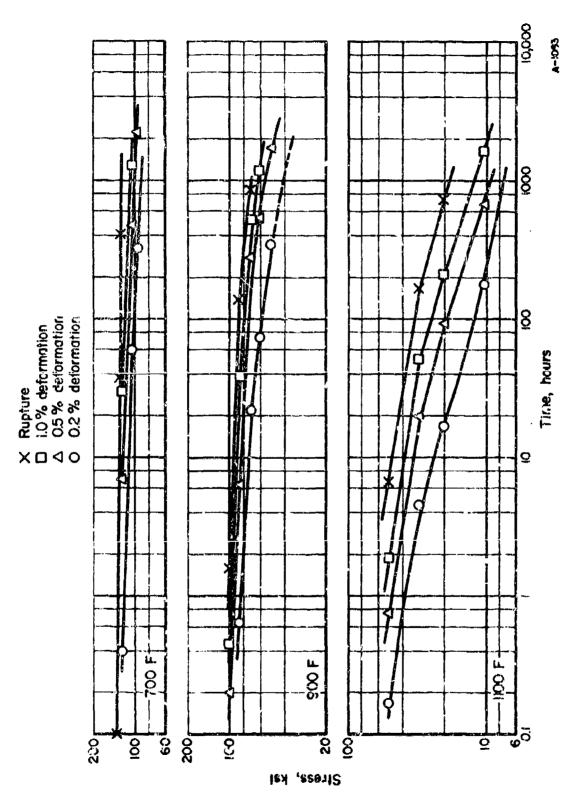


FIGURE 9. AXIAL LOAD FATIGUE BEHAVIOR FOR NOTCHED (K = 3.0) 15-5 PH (H1025) FORGED BAR



STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 15-5 PH (H1025) FORGED BAR (TRANSVERSE) FIGURE 10.

HP 9Ni-4Co-0.20C Alloy Steel

Material Description

HP 9Ni-4Co-0.20C steel was developed specifically to have high hardenability combined with good fracture toughness. It can be welded in the fully heat-treated condition and achieve essentially 100 percent joint efficiency without preheat or postheat treatment. The 0-20C grade is available as sheet, strip, plate, bars, forginge, and tubing.

The material used for this program was consumable electrode vacuum melted and from Republic Steel Heat 3821003. It was obtained as a 2-1/4 inch x 6-inch x 84 inch forged bar and had the following composition:

Chemical	
Composition	Percent
Carbon	0.19
Manganese	0.36
Phosphorus	0.008
Sulfur	0.007
Silicon	0.04
Nickel	9.30
Chromium	0.80
Molybdenum	1.04
Vanadium	0.08
Cobalt	4.70
Iron	Balance

Processing and Heat Treating

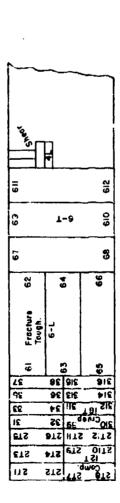
The specimen layout for this alloy is shown in Figure 11. Specimens were rough machined in the as-received annealed condition, heat treated as follows:

- (1) normalize at 1650 F, 1 hour, air-cool,
- (2) austenitize at 1500 F, 1 hour, oil quench,
- (3) single temper at 1025 F, 6 hours, air cool and then finish machined.

Test Results

Tension. Results of tension tests in the longitudinal and transverse directions at room temperature, 500 F, 700 F, and 900 F are given in Table IX.

21.2	21.4	216	21.8	2L9 2L10	12
ll		6	121	2	_
115 211	L4 2L3	16 215	2.7	LIO 2L9	ורוב ברוו ברוב
12	5	-	الال	11.10	1
		Tension	121		
_	L3	5.	~	6	=
	<u> </u>	=	بشا	3171 =	17
611				3171	
211				811	
511				911	Charpy's
ETI				\$ ±1	3
111				112	
60				_	999
495					923
581	<u> </u>				988
50					284
188					299
6+					220
120					8 48
90					949
43					244
38					245
32					226
90					929
33					224
188			_		238
62	ç				930
12	ç.		109		929
52	ç		6110	4	9ZG
23	ç				254
121	;				228
612					250
219	G				818
GIG					910
£113	5				PIS
11.8	; 				213
66					018
25					99
Se					96
5.5					70
118					25
١.			9-		



8-(373

FIGURE 11. SPECIMEN LAYOUT FOR HP 9NI-4Co-0.20C FORGED BAR

Stress-strain curves at temperature are presented in Figures 12 and 13. Effect-of-temperature curves are shown in Figure 16.

Compression. Results of compression tests in the longitudinal and transverse directions at room temperature, 500 F, 700 F, and 900 F are given in Table X. Compressive stress-strain and tangent modulus curves at temperature are presented in Figures 14 and 15. Effect-of-temperature curves are shown in Figure 17.

Shear. Test results for pin shear tests in both the longitudinal and transverse directions at room temperature are given in Table XI.

Impact. Charpy test results at room temperature for longitudinal and transverse specimens are given in Table XII.

Fracture Toughness. Results of six slow-bend type tests are given in Table XIII. The size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, therefore the K_Q value in the table is not a valid K_{IC} value by existing ASTM criteria.

Fatigue. Axial-load fatigue tests were conducted at room temperature, 500 F, and 700 F for transverse specimens, both unnotched and notched. Results are given in tabular form in Tables XIV and XV. S-N curves are presented in Figures 18 and 19.

Creep and Stress Rupture. Tests were performed at 500 F, 700 F, and 900 F for transverse specimens. Tabular test results are given in Table XVI. Log-stress versus log-time curves are presented in Figure 20.

Stress Corrosion. Specimens were tested as described in the experimental procedure section of this report. No failures or crecks occurred in the 1000 hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this steel is 6.4×10^{-8} in/in/F for 80 F to 900 F.

Density. The density of this alloy is 0.284 1b/in3.

TABLE IX. TENSILE TEST RESULTS FOR HP 9N1-4Co-0.20C FORGED BAR

Specimen No.	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 inches, percent	Reduction in Area, percent	Tensile Modulus 10 ⁶ psi
	L	ongitudinal at l	Room Temperatur	2	
111	198.0	181.0	17.5	67.1	28.0
1L-2	196.0	181.0	17.5	68,2	26.6
1L-3	197.0	180.0	17.5	68.4	26.4
]	Transverse at Ro	oom Temperature	1	
1T-1	197.0	180.0	14.5	55.0	27.9
1T-2	197.0	180.0	14.5	56.3	27.7
1T-3	197.0	180.0	15.0	57.1	26.4
		Longitudina	l at 500 F		
1L-4	178,0	165.0	16.0	66.7	25.4
1L-5	182.0	1.65,0	16.0	65.4	26.0
1L-6	179.0	165.0	15.5	64.4	26.7
		Transverse	at 500 F		
1.T-4	179.0	166.0	14.0	56.0	25.7
1T-5	179.0	166.0	14.0	55.1	25.8
1T-6	179.0	166.0	14.0	55.8	26.2
		Longitudina	1 at 700 F		
1L-7	172.0	155.0	16.9	64.4	24.0
1L-8	170.0	155.0	16.5	69.4	24.3
1L-9	169.0	156.0	16.0	66.4	24.6
		Transverse	at 700 F		
1T-7	169.0	151,0	14.5	58.4	24.9
1T-8	169.0	154.0	14.5	57.4	24.8
1T-9	168.0	153.0	14.5	57. 7	24.4

TABLE IX. (Concluded)

Specimen	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 inches, percent	Feduction in Area, percent	Tensile Modulus, 10 ⁶ psi
		Longitudina	1 at 900 F		
1L-10	148.0	130.0	18.0	69.6	22.2
1L-11	148.0	130.0	18.0	69.9	22.2
1L 12	147.0	129.0	18.0	39.9	21.7
		Transverse	at 900 F		
1T-10	147.0	128.0	16.0	61.2	25.3
1T-11	1/:7.0	128.0	16.0	59.5	23.4
1T-12	147.0	131.0	16.0	60.6	22.7

TABLE X. COMPRESSION TEST RESULTS FOR HP 9N1-4Co-0.20C FORGED BAR

	0.2 Percent	_
	Offset Yield	•
Specimen.	Strength,	Modulus,
No.	ksi.	10 ⁶ psi
Longit	dinal at Room Ter	perature
2L-1	196.0	27.6
2L-2	198.0	27.7
2L-3	196.0	28.0
Trans	verse at Room Tem	perature
2T-1	194.0	27,1
2T-2	195.0	28.6
21-3	195.0	28.2
Ī	ongitudinal at 50	0 F
2L-4	169.0	25.7
2L-5	173.0	26,5
216	173.0	26.9
	Transverse at 500	F
2T-4	171.0	27.0
21-5	171.0	25.9
2T-6	172.0	25.7
ì	ongitudinal at 70	00 F
217	162.0	24.8
2L -8	158.0	25.5
2L-9	157.0	25,0
	Transverse at 700	F
2T-7	159.0	25.1
2T -8	156.0	24.9
2T-9	159.0	25.9

TABLE X . (Concluded)

0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10 ⁶ psi
ongitudinal at 90	00 F
137.0	23.3
135.0	24.8
134.0	25.0
Transverse at 900	F
136.0	23.2
135.0	24.5
136.0	24.4
	Offset Yield Strength, ksi ongitudinal at 90 137.0 135.0 134.0 Transverse at 900 136.0 135.0

TABLE XI. SHEAR TEST RESULTS FOR HP 9N1-4Co-0.20C FORGED BAR

Specimen No.	Ultimate Shear Strength, ksi
Lo	ongitudinal
4L-1	123.0
4L-2	124.0
4L-3	124.0
<u>1</u>	ransverse
4T-1	120.0
4T-2	124.0
4T-3	123.0

TABLE XII. IMPACT TEST RESULTS FOR HP 9N1-4Co-0.20 C FORGED BAR

pecimen Number	Energy, ft/lbs
Longitud	inal
10L-1	73.0
10L-2	37.0
10L-3	62.0
10L-4	63.0
10L-5	77.0
Transve	erse
10T-1	50.0
10T-2	54.0
10T-3	52.0
10T-4	56.0
10T-5	54.0

TABLE XIII. FRACTURE TOUGHNESS TEST RESULTS FOR HP 9N1-4Co-0.20C FORGED BAR

Specimen Number	W, inches	ä, inches	T, inches	P, 1bs	Span, inches	$f(\frac{a}{w})$	K _Q (a)
			Transv	erse			
3T	1,254	.648	,631	6,650	5	2.8	107.3
2T	1.255	, 640	, 632	7,450	5	2.7	115.3
1т	1.255	. 692	.631	8,200	5	3.1	146.3
		··,	Longitu	dinal			
2L	1.504	.861	755 ۽	12,650	6	3.4	186.1
3 L	1,502	.870	.755	12,800	. 6	3.5	193.4
1T.	1.504	.735	.757	9,450	6	2.5	104,3

⁽a) Candidate fracture toughness values, K_Q , are invalid as K_{Ic} values since a, T, <2.5 $\binom{K_Q}{TYS}$.

TABLE XIV. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED HP 9N1-4Co-0.20C FORGED BAR (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-1	120	26,900
5-2	110	23,900
5-3	100	34,000
5-4	90	58,200
5-5	. 80	69,900
5-6	70	124,100
5 - 7	60	5 024 900
5-8	50	11,920,400 ^(a)
	500 F	
5-17	140	12,000
5-19	135	23,600
5-18	130	21,100
5-20	125	17,400
5-16	120	10,115,000 ^(a)
5-14	100	. 109.000
5-15	100	12,916,000 ^(a)
	700 F	
5-26	180	30,000
5-25	160	746,400
5-24	150	360,900
5-22	140	25,600 ^(b)
5-23	140	2,052,400
5-21	130	2,702,000
5-27	120	50.800
5-28	120	10,277,000 ^(a)

⁽a) Did not fail,

⁽b) Failed at thermocouple.

TABLE XV. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED ($K_t = 3.0$) HP 9Ni-4Co-0.20C FORGED BAR (TRANSVERSE)

Specimen Number	Maximum Stress, k si	Lifetime, Cycles
	Room Temperature	:
5-31	90	11,900
5-37	85	17,900
5-32	80	21,400
5 _~ 35	75	13,300
5 - 3.3	70	21,600
5-36	65	50,900
5-34	60	12,381,800 ^{(a}
	500 F	
5 -41	90	7,800
5-42	85	11,600
5-43	80	27,300
5 -44	75	13,200
5-45	76	25,200
5-46	65	34,400
5 -4 7	60	31,300
5-48	50	99,000
5-59	40	60,600
5-60	40	109,900
5-61	30	10,850,900 ^{(a}
	700 F	
5 -5 1	9 0	10,900
5-52	80	14,400
5 - 53	75	32,400
5-54	70	1,699,300
5-55	65	28,100
5-56	65	85,200
5-57	60	51,900
5 - 58	50	12,986,000 ^{(a}

⁽a) Did not fail,

山城 好是我想像你是我回答的好是我的好要不是好了是一个人们的时候一个一个人们要是 後妻 可見りょう 人名日本 大家主義

SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES OF HP 9NI-4Co-0.20 FORGED BAR (TRANSVERSE) TABLE XVI.

Specimen S	Stress.	Temper-	Hou	Hours to Ind	dicated Creep Deformation, percent	p Deformat	loa,	Initial Strain,	Rupture Time.	Elongation in 2 in.	Reduction of Area.	Minimum Creep Race,
nc.	ksi	fa,	0.1	0.2	0.5	1.0	2.0	Percent	hr	percent	percent	percent/hr
3-3		500	:			i	i		On Loading	8.9	44.7	
3-5	160	200	0,03	0.10	2750 ^(b)	1	:	1,828	816,5(a)	2.245	i	0.00053
3-10	145	200	120	(_Q)0057	i	8 0 8	; ;	0.611	793.9	0.748	<u>.</u>	0.00015
3.1	160	700	0.01	0.02	0.0	0.33	1.5	1.871	8.1	12.6	58.1	0.65
34	150	700	\$ 0	0.13	1.5	17.5	6. 5.	1.044	250.7	16.3	56.6	0.015
3-7	125	902	1.5	21	360	1370 ^(b)	:	0.563	431.5(8)	1.092	ŧ	0,00044
3-9	105	200	8	350	2650 ^(b)	:	1	0.544	598.7(8)	0.777	1	0.00013
3-2	120	006	0.02	0.02 0.04	0.12	0.30	0.67	1.015	1.5	12.6	58.4	2.6
3-6	36	006	0,15	0.7	12	67	92	0.552	100.7	4.4	7.9	C.013
3-8	80	006	1.5	13.5	120	278	659	0.478	478.0	3.7	5.6	0.0027
3-11	\$\$	006	. 25	140	640	1650 ^(b)	:	00:300	358.3(4)	0.630	•	0.00062
3-12	35	900	270	240	1700 ^(b)	4100(b)	. !	0,207	763.9(8)	0.415	i	0.00021

(a) Test discontinued.(b) Estimate.

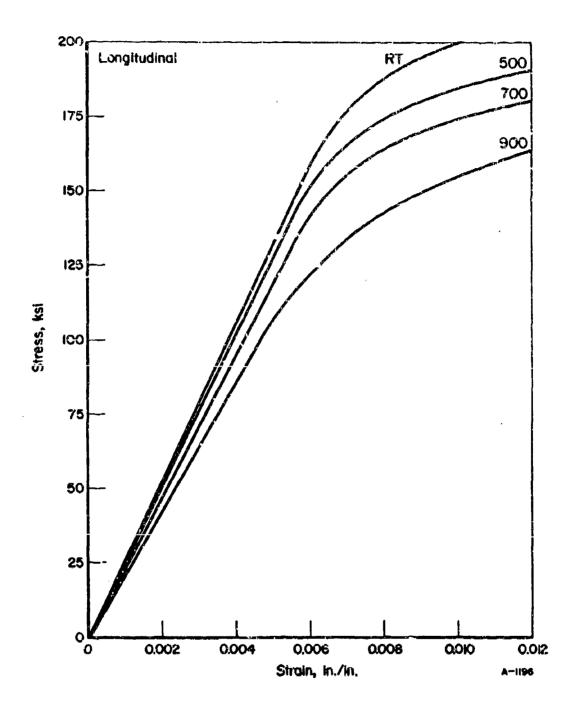


FIGURE 12. TYPICAL TENSILE STRESS-STRAIN CURVES FOR HP 9N1-4Co-0.20C FORGED EAR (LONGITUDINAL)

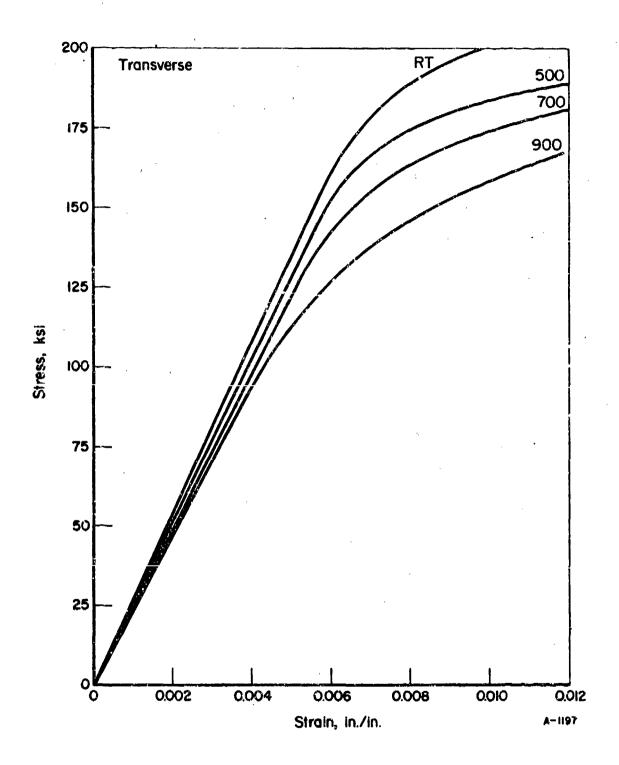


FIGURE 13. TYPICAL TENSILE STRESS-STRAIN CURVES FOR HP 9Ni-4Co-0.20C FORGED BAR (TRANSVERSE)

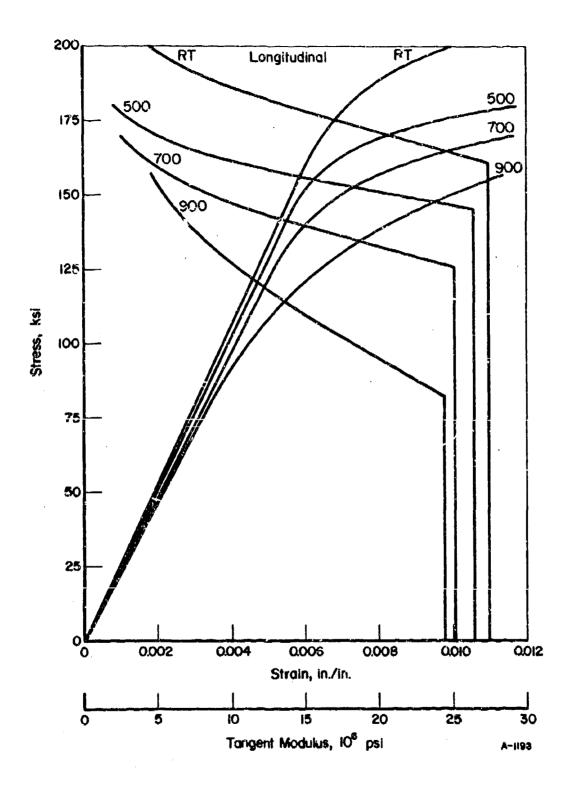


FIGURE 14. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FCR HP 9N1-4Co-0.20C FORGED BAR (LONGITUDINAL)

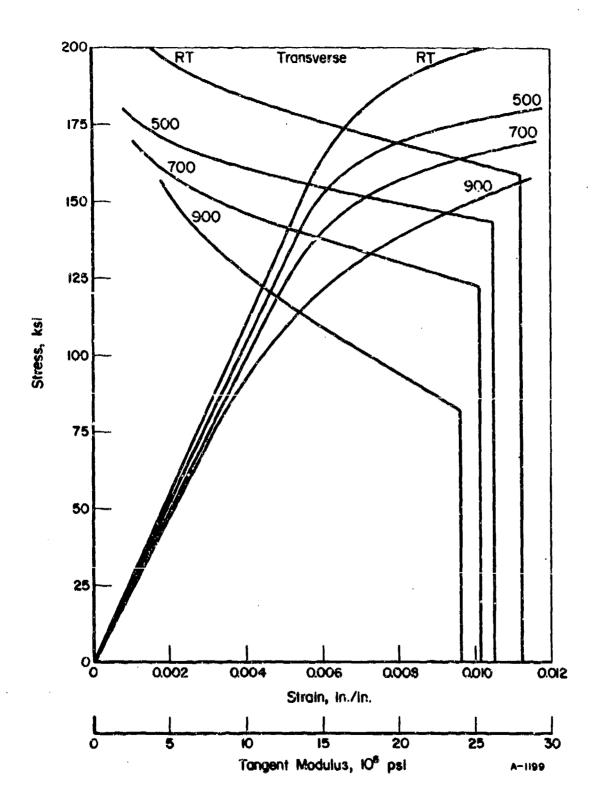


FIGURE 15. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR HP 9N1-4Co-0.20C FORGED BAR (TRANSVERSE)

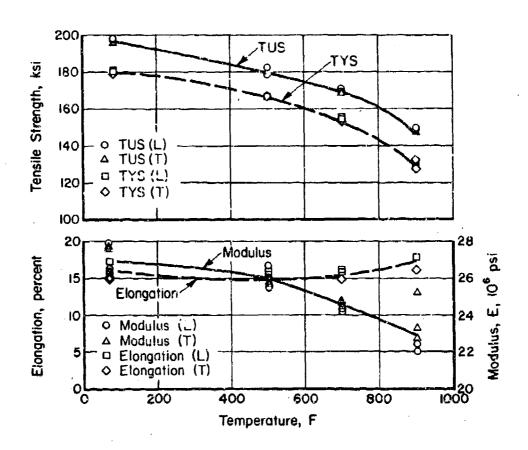


FIGURE 16. EFFECT OF TEMPERATURE ON THE TENSILE PROP-ERTIES OF HP 9N1-4Co-0.20C FORGED BAR

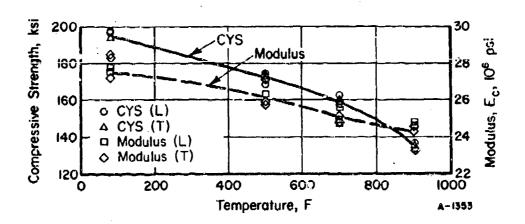


FIGURE 17. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF HP 9N1-4Co-0.20C FORGED BAR

a come and the contract of the foreign that the contract of th

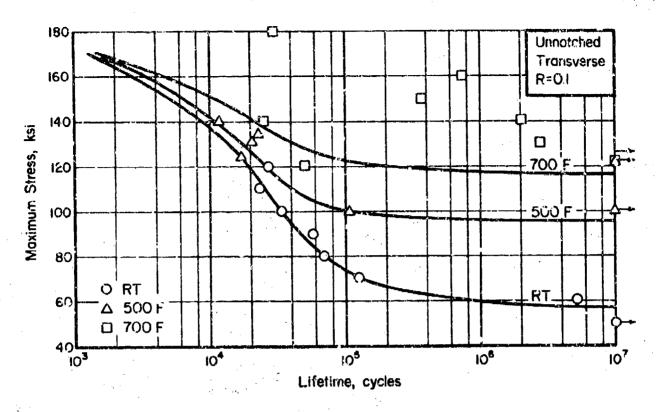


FIGURE 18. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED HP 9N1-4Co-0.20C FORGED BAR

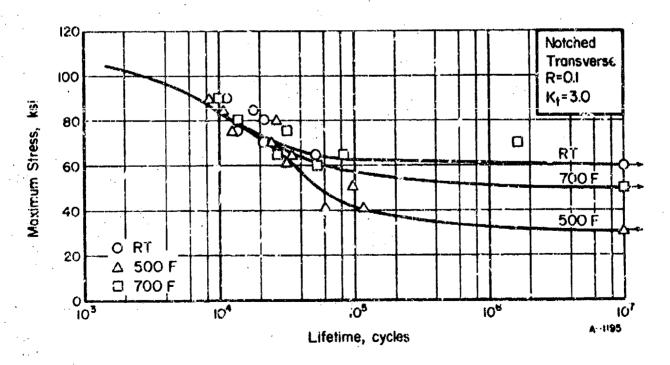
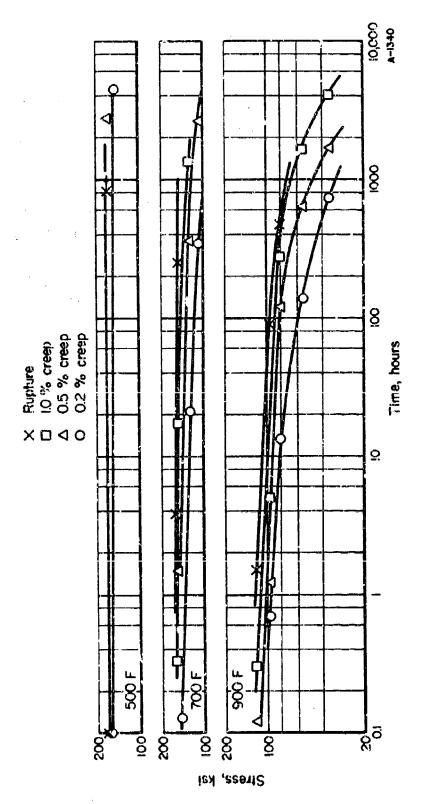


FIGURE 19. AXIAL LOAF FATIGUE RESULTS FOR NOTCHED (Kt => 3.0) HP 9N1-4Co-0.20C FORGED BAR



STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR HP 9N1-4Co-0.20C FORGED BAR (TRANSVERSE) FIGURE 20.

PH 13-8 Mo Stainless Steel

Material Description

This alloy is a martensitic precipitation hardenable stainless steel developed by the Armco Steel Corporation. It can be heat treated to high strength levels and exhibits good ductility in the transverse direction. This transverse direction toughness is obtained by composition balance designed to prevent formation of delta ferrite in the structure, low carbon content to minimize grain boundary carbide precipitation, and double vacuum melting to reduce alloy segregation. The alloy reportedly has excellent resistance to stress corrosion cracking in synthetic seawater and excellent resistance to corrosion in a 5 percent salt spray environment.

The material used in this evaluation was obtained as a 4-inch x 5-inch x 5 foot forged bar from Armco Heat 1W0241. The composition was as follows:

Chemical	
Composition	Percent
Carbon	0.035
Manganese	0.01
Phosphorus	0.002
Sulfur	0.003
Silicon	0.02
Chromium	12.62
Nickel	8.24
Molybdenum	2.16
Aluminum	1.02
Iron	Balance

Processing and Heat Treating

The specimen layout for PH 13-8 Mo is shown in Figure 21. Specimens were machined in the as-received condition A and then heat treated at 1000 F for 4 hours to Condition H 1000.

Test Results

Tension. Results of tests in the longitudinal and transverse directions at room temperature, 500 F, 700 F, and 900 F are given in Table XVII. Tensile stress-strain curves at temperature are shown in Figures 22 and 23. Effect-of-temperature curves are presented in Figure 26.

Compression. Test results are given in Table XVIII for longitudinal and transverse specimen; at room temperature, 500 °, 700 F, and 900 F. Compressive stress-strain and tangent modulus curves at temperature are presented in Figures 24 and 25. Effect-of-temperature curves are shown in Figure 27.

*	P26	344	11.4		21 21 21 215
95	825	548	ILB Tensile	*·11	2.5 Comp. Fr
512	90613D± 286	293	ורג	2) 100 <u>1</u>	ာ နေ
916	966	999	Creep 15 Shear		Charpy 61 Fracture
250	075	560	31-315	म्ब मा	\$ 2
					B-1371

FIGURE 21. SPECIMEN LAYOUT FOR PH 13-8 Mo (H1000) FORGED BAR

343 SM 513 SM

Shear. Results of pin shear tests at room temperature for longitudinal and transverse specimens are shown in Table XIX.

Impact. Charpy test results are shown in Table XX.

Fracture Toughness. Results of slow-bend type tests are shown in Table XXI. The size ratio, 2.5 $(K_0/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, therefore, the K_0 value shown in the table is not a valid K_{T_0} value by existing ASTM criteria.

Fatigue. Axial load fatigue tests were conducted at room temperature, 400 F, and 700 F for transverse specimens, both unnotched and notched. Test results are given in Tables XXII and XXIII. S.N curves are shown in Figures 28 and 29.

Creep and Stress Rupture. Tests were preformed at 500 F, 700 F, and 900 F for transverse specimens. Tabular test results are given in Table XXIV. Log-stress versus log-time curves are presented in Figure 30.

Stress Corrosion. Specimens were tested as described in the experimental procedure section of this report. No failures or cracks occurred in the 1000 hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 6.6 x 10 s in/in/F for 80 F to 900 F.

Density. The density of this material is 0.279 lb/in3.

TABLE XVII. TENSILE TEST RESULTS FOR PH 13-8 Mo (H1000) FORGED BAR

Specimen Number	Ultimate Tensile Strength, ksi	0.2 percent Offset Yield Strength, ksi	Elongation in 2 inches, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁶ psi
	Lor	ngitudinal at Ro	om Temperature		
1L-1	194.0	190.0	13.0	49.5	27.7
112	193.0	187.0	14.5	58.5	. 27.6
1L-3	191.0	185.0	12.5	47.5	. 27.9
	Lyn	Transverse at	Room Temperatur	<u> </u>	
1T-1	192.0	187.0	13.0	51.0	27.3
1T-2	188.0	179.0	14.5	55.5	28,3
1T-3	191.0	184.0	14.0	56.0	28.4
		Longitudinal	at 500 F		
1L-4	170.0	165.0	12.5	58.0	27.4
1L-5	169.0	164.9	13.0	59.0	27,3
1L-6	168.0	165.0	12,0	53.0	26.5
		Long Transver	se at 500 F	•	
1T-4	168.0	162.0	11.0	49.5	25.2
1T~5	166.0	163.0	12.5	56.0	25.5
1T-6	171.0	166.0	11.0	50.0	25.2
		Longitudinal	at 700 F		
1L-7	158.0	148.0	14.0	59.5	24.7
1L-8	158.0	153.0	11.0	45.0	24.9
1L~9	157.0	153.0	13.0	55.0	25.8
		Long Transver	se at 700 P		
1T-7	159.0	148.0	12.0	51.0	26.2
1T-8	156.0	150.0	12.5	50.0	24.7
1T-9	157.0	151.0	13.0	56.0	24.4
		Longitudinal	at 900 F		
1L-10	129.0	119.0	21.0	71.5	22.1
1L-11	129.0	119.0	21.5	69.0	20.7
1112	127.0	119.0	21.0	71.0	22.8
	•	Long Transver	se'at 900 F		
1T-10	125.0	116.0	22.5	72.0	20.4
1T-11	128.0	120.0	22.0	71.0	22.3
1T-12	128.0	118.0	20,0	68.5	21.6

TABLE XVIII. COMPRESSION TEST RESULTS FOR PH 13-8 Mo (H1000) FORGED BAR

	0.2 Percent	
	Offset Yield	Compression
Specimen	Strength,	Modulus,
No.	ksi	10 ⁶ psi
Longitu	dinal at Room Tem	perature
2L-1	183.0	30.8
2L-2	193.0	30.6
2L-3	187.0	28.7
Long Tra	nsverse at Room T	emperature
2T-1	199.0	29.9
2T-2	198.0	30.0
2T-3	202.0	30.0
L	ongitudinal at 500	F
2L-4	160.0	25.9
2L-5	155.0	26.1
216	160.0	26.6
<u>Lon</u>	g Transverse at 5	00 F
2T-4	170.0	25.9
2T-5	170.0	25.8
2T-6	169.0	25 .4
Ŀ	ongitudinal at 700	<u>) F</u>
2L-7	148.0	25.8
2L-8	157.0	25.8
2L-9	147.0	25.7
Lor	ng Transverse at	700 F
2T-7	160.0	23.6
2T-8	159.0	25,2
2T-9	157.0	24.5
		-

TABLE XVIII. (Concluded)

Specimen No.	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10 ⁸ psi
Lo	ngitudinal at 900	F
2L-10	120.0	22.6
2L-11	115.0	23.2
2L-12	120.0	23.7
Long	Transverse at 9	00 F
2T-10	122.0	23.1
2T-11	119.0	23.0
2T-12	123.0	23.0

TABLE XIX. SHEAR TEST RESULTS FOR PH 13-8 Mo ^(H1000) FORGED BAR

Specimen Number	Ultimate Shear Strength, ksi
Lo	ngitudinel
4L-1	122.0
4L-2	122.0
4L-3	120.0
Long	Transverse
4T-1	123.0
4T-2	123.0
4T-3	123.0

TABLE XX. IMPACT TEST RESULTS FOR PH 13-8 Mo (H1000) FORGED BAR

pecimen Number	Energy ft/lbs
Longit	udinsl
10L-1	36.0
10L-2	35.5
10L-3	34.5
1GL-4	33,5
10L~5	31.0
10L-6	33.5
Long Tr	ensverse
10T~1	28.0
10T-2	28.0
101-3	26.0
10T-4	28,0
10T-5q	29.0
10T~6	27.0

TABLE XXI. FRACTURE TOUGHNESS TEST RESULTS FOR PH 13-8 Mo (H1000) FORGED BAR (LONGITUDINAL)

Specimen Number	W, inches	a, f ches	T, inches	P, lbs	Span, inches	$f(\frac{a}{w})$	KQ(a)
5L	1.500	.879	.742	10,750	6	3,5	169.0
41.	1.501	.880	.741	10,500	6	3.6	166.0
3L	1.499	.868	.741	10,300	6	3,5	158.9
21.	1.500	.871	.741	9,800	6	3,5	151.9
1L	1.499	.870	.741	10,500	6	3,5	162.8

⁽a) Candidate fracture toughness values, \overline{K}_Q , are invalid as K_{Ic} values since a, T, <2.5 $\binom{K_Q}{TYS}$.

TABLE XXII. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED PH 13-8 Mo (H1000) FORGED BAR (LONGITUDINAL)

Specimer Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-1	215.0	14,490
5 - 2	. 210.0	26,120
5-3	205.0	35,190
5-4	200.0	61,570
5-5	195.0	65,470
5-6	190.0	247,050
5-7	180.0	333,530
5-8	175.0	4,404,800
5-9	170.0	785,900
5-10	170.0	730,900
5-11	160.0	458 000
5-12	150.0	10,010,000 ^(a)
	400 F	
5-15	200.0	100
5-14	'190.0	17,400
5-12	180.0	151,000
5-11	170.0	42,900
5-16	170.0	1,015,600
5-18	165.0	10,329,900 ^(A)
5-17	160.0	10,407,300 ^(a)
	700 F	
5-22	170.0	(b)
5-26	165.0	200
5-24	160.0	33,960
5-2L	155.0	28,900
5-29	150.0	945 500
5-23	150.0	10,090,700 (a)

⁽a) Did not fail.

⁽b) Failed on loading.

TABLE XXIII. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K = 3.0) PH 13-8 Mo (H1000) FORGED BAR (LONGITUDINAL)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-1	180.0	1,410
5-2	160.0	1,900
5-3	140.0	3,800
5 - 5	120.0	7,910
5-6	100.0	32,830
5 - 7	80.0	72,800
5 - 8	60 .0	210,000
5 -9	50 .0	17,555,600 ^(A)
	400 F	
5-11	180.0	1,100
5-12	170.0	1,700
5~13	160.0	1,800
5-14	140.0	1,350
5-15	120.0	1,500
5-16	100.0	8,100
5-17	90.0	26,400
5 -18	80.0	60,500
5-20	70.0	14.754.700
5-19	60.0	10,192,200 ^(a)
	700 F	
5-21	100.0	3,900
5-23	90.0	18,300
5-26	85.0	16,900
5-22	80.0	599,800
5 - 27	75.0	1,344,700
5 - 24	70.0	5 358 700
5 - 25	60.0	14,928,700 ^(a)

⁽a) Did not fail.

SUMMARY DATA ON CRESP AND RUPTURE PROPERTIES OF PH 13-8 Mo (H1000) FORGED BAR (LONGITUDINAL) TABLE XXIV.

Specimen		H	ĺ	s to Indic	c Indicated Creen Deformation,	Deformat	í on,	Initial Strain,	Rupture Time,	Elongation in 2 fn.,	Reduction of Area,	Minimum Croep Rate,
. Nc.	ksí	£.	0.1	0.2	0.5	1.0	2.0	percent	hr	percent	percent	percent/hr
3-3	171,5	200	:	2	1	!	1	· i	On Loading	9.6	44.2	ł
3,5	165	503	;	*	;	1 2	:	:	0.01	9.6	54.7	;
3-5	160	200	0.17		107	1100	į	\$06.0	1078,0(4)	1.897	4	0.00025
3-10	140	200	2000 ^(b)	(5)0057	į. t	* * * * * * * * * * * * * * * * * * *	į	0,763	1027.5(8)	0.822	1	0.00004
3-8	140	700	0.07	0,25	1,1	ه. ه.	10	98.0	29.4	14.8	61.4	0.16
3-2	120	ĸ	17	15	130	725	4230(b)	0.571	836.5(4)	1.585	t en	0.0003
3-9	ę,	700	70	620	3600 ^(b)	į	4 2 6	6.507	667.6 (a)	0.714	i	0.00010
د. بر	0 0	Ç	•	. 0.08	C.	4 0	o.	0.637	ব	21.5	80 61	£(,
3-1	ů.	906	6.2	0.0	3.5	9.5	B.	0.263	196.3	6.63	68.5	0.044
3-7	<u>د</u> ک	006	1.0	3,3	30	175	240	6.277	1012.8(8)	2,85	i 4	0.0018
179 179 179	90	900	\$\$	625	2600 ^(b)	1 2 0	1 2 4	0,033	524.8(3)	0.233	; •	0.00015

(a) Test discontinued. (b) Estimate.

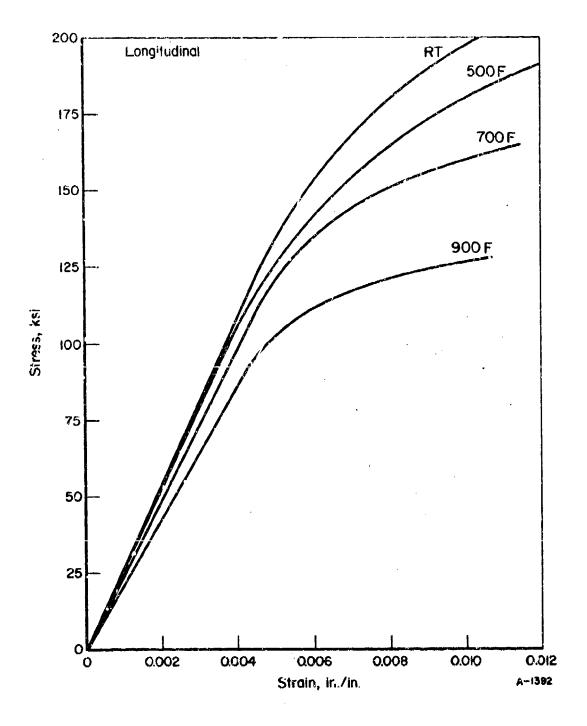


FIGURE 22. TYPICAL TENSILE STRESS-STRAIN CURVES FOR PH 13-8 Mo (H1000) FORGED BAR (LONGITUDINAL)

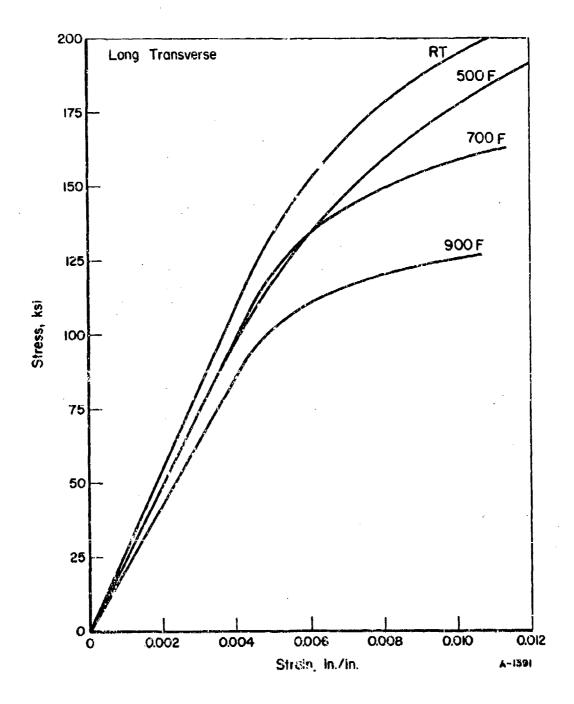


FIGURE 23. TYPICAL TENSILE STRESS-STRAIN CURVES FOR PH 13-8 Mo (H1000) FORGED BAR (LONG TRANSVERSE)

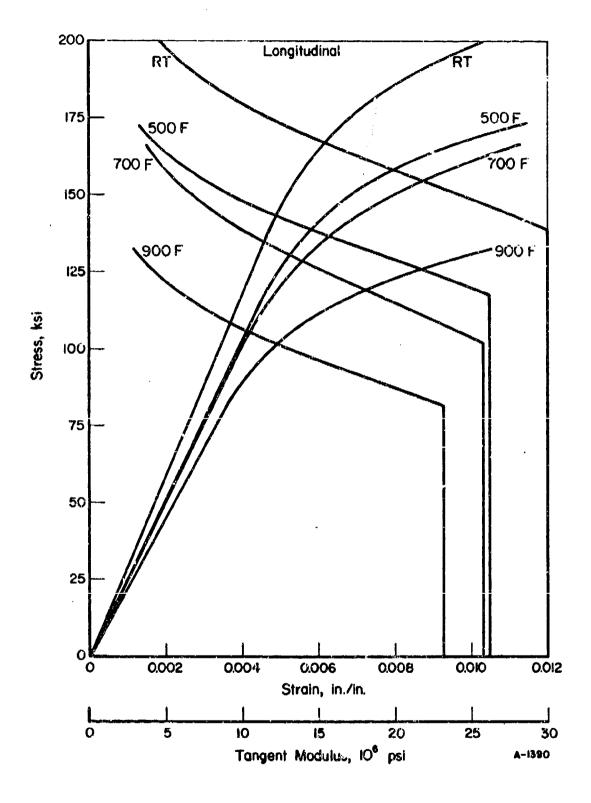


FIGURE 24. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR PH 13-8 Mo (H1000) FORCED BAR (LONGITUDINAL)

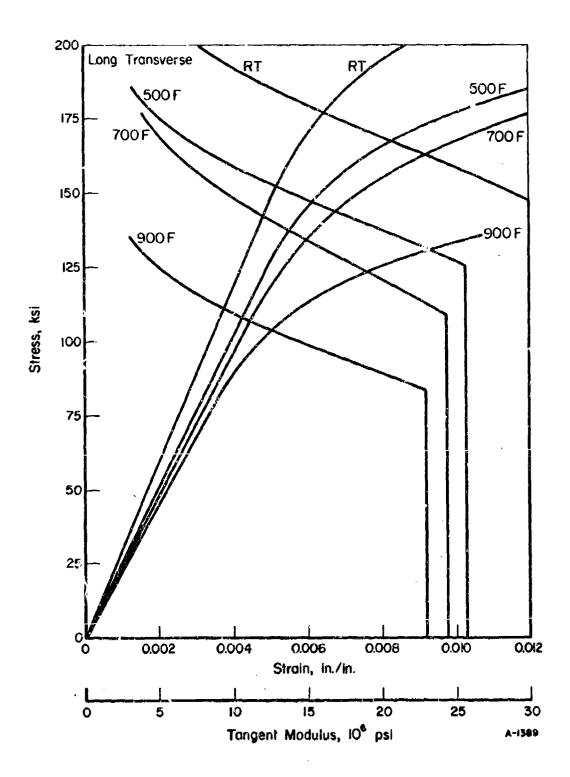


FIGURE 25. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR PH 13-8 Mo (H1000) FORGED BAR (LONG TRANSVERSE)

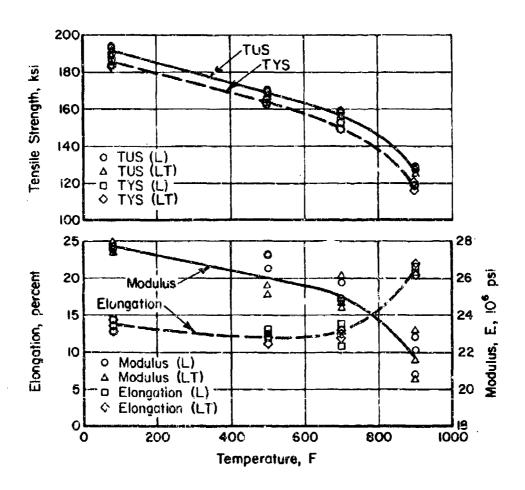


FIGURE 26. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF PH 13-8 Mo (H1000) FORGED BAR

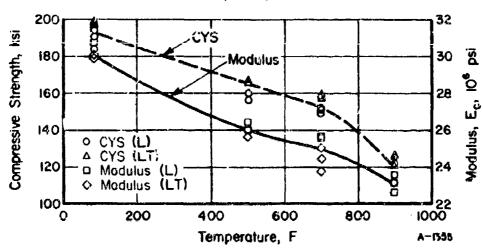


FIGURE 27. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF PH 13-8 Mo (H1000) FORGED BAR

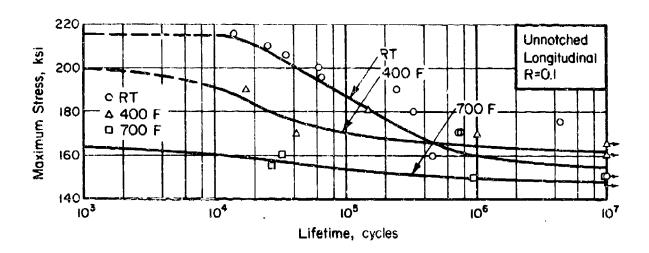


FIGURE 28. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED PH 13-8 Mo (H1000) FORGED BAR

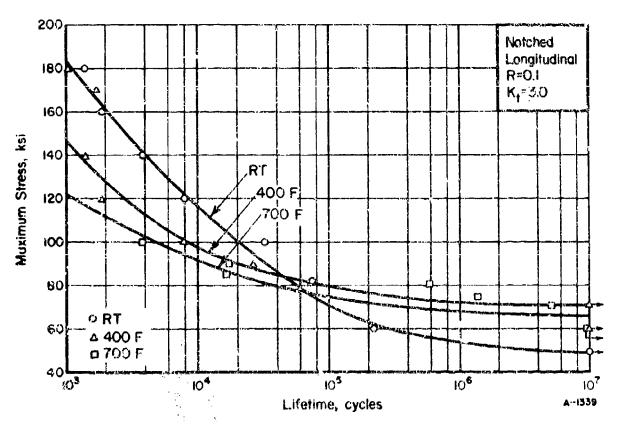
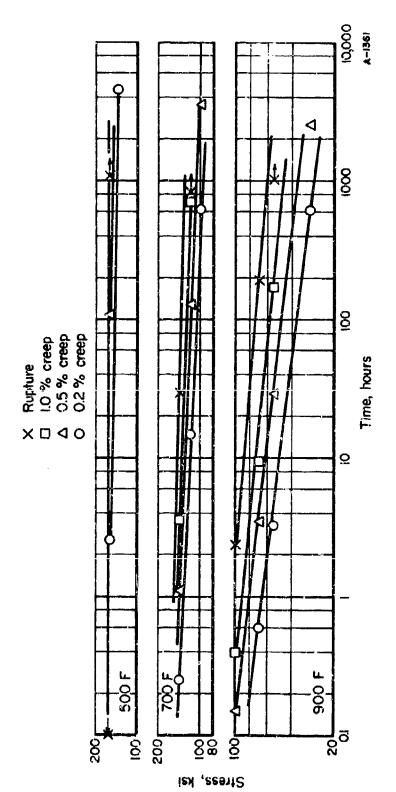


FIGURE 29. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (Kt = 3.0) PH 13-8 Mo (H1000) FORGED BAR



STRESS-RUPTURE AND CREEP DEFCRMATION CURVES FOR PH 13-8 Mo (H1000) FORGED BAR (LONGITUDINAL) FIGURE 30.

7049-T76 Aluminum Extrusions

Material Description

Alloy 7049 was developed by Kaiser Aluminum and Chemical Corporation to have a strength level in the range of 7075-T6 and 7079-T6 coupled with a high resistance to stress corrosion cracking. Initial development and production was in the form of forgings and hand forgings. Further development has been in plates and extrusions.

The material evaluated was a 4-inch x 4-inch extrusion supplied by Kaiser with the following composition:

Chemical							
Composition	Percent						
Zinc	7.6						
Magnesium	2.5						
Copper	1.5						
Chromium	0.15						
Silicon	0.25 max						
Iron	0.35 max						
Titanium	0.10 max						
Manganese	0.20 max						
Aluminum	Balance						

Processing and Heat Treating

The specimen layout for 7049 is shown in Figure 31. Specimens were tested in the as-received -T76 temper.

Test Results

Tension. Test results for longitudinal and transverse specimens at room temperature, 250 F, 350 F, and 500 F are given in Table XXV. Room temperature short transverse tensile test results are also given in Table XXV. Stress-strain curves at temperature are presented in Figures 32 and 33. Effect-of-temperature curves are shown in Figure 36.

Compression. Test results for longitudinal and transverse specimens at room temperature, 250 F, 350 F, and 500 F are given in Table XXVI. Compressive stress-strain and tangent modulus curves at temperature are presented in Figures 34 and 35. Fffect-of-temperature curves are presented in Figure 37.

Shear. Pin shear test results for longitudinal and transverse specimens at room temperature are shown in Table XXVII.

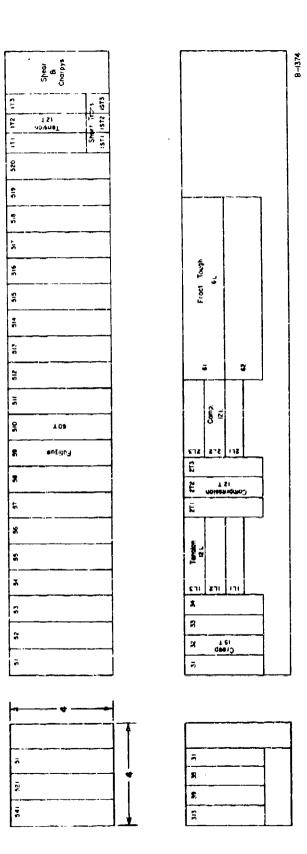


FIGURE 31. SPECIMEN LAYOUT FOR 7049-T76 EXTRUSIONS

or and the second resources to the second
Impact. Charpy test results for longitudinal and transverse specimens at room temperature are shown in Table XXVII.

Fracture Toughness. Slow-bend type tests curve performed for six longitudinal specimens. Results are shown in Table XXIX. Since the size ratio, 2.5 $({\rm K_Q/TYS})^2$, was greater than both the specimen thickness and crack length in all tests, the ${\rm K_Q}$ values are not valid ${\rm K_{Ic}}$ values by existing ASTM criteria.

Fatigue. Axial-load fatigue tests were conducted on transverse specimens at room temperature, 250 F, and 350 F. Tabular test results are presented in Tables XXX and XXXI. S-N curves are shown in Figures 38 and 39.

Creep and Stress-Rupture. Results for transverse tests at 250 F, 350 F, and 500 F are shown in Table XXXII. Log-stress versus log-time curves are presented in Figure 40.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000 hour test duration.

Thermal Expansion. Coefficient of thermal expansion for this alloy is 12.9×10^{-8} in/in/F for 80 F to 212 F.

Density. The density for this material is 0.099 lb/in3.

TABLE XXV. TENSILE TEST RESULTS FOR 7049-T76 EXTRUSIONS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁸ psi
		Longitudinal at Re	oom Temperature		
1L-1	81.1	72.2	13.0	35.9	10.6
1L-2	82.1	74.6	13.0	34.7	11.0
1L-3	86.9	81.0	12.0	36.3	10.5
		Transverse at Ro	oom Temperature		•
1T-1	76.2	67.2	11.5	23.3	9.5
1T-2	76.2	67.7	11.0	23.2	9.9
1T~3	76.2	67.4	11.0	23.3	10.2
	<u>s</u>	hort Transverse a	t Room Temperat	ure	
1ST-1	76.2	68.0	12.0	22.6	10.4
1ST-2	76.4	67.8	12.0	22.6	10.3
1ST-3	76.2	67.4	11.0	22.6	10.6
		Longitudina	1 at 250 F		
1L-4	64.1	62.6	22.0	52.4	9.5
1L-5	64.4	63.3	22.0	52.6	9.0
1L-6	64.6	63.8	22.5	54.2	9.5
		Transverse	at 250 F		
11-4	58.4	56.0	15,5	34.1	9.3
1T-5	58.4	56.4	18,0	34.5	9.4
1 T-6	59.9	56.8	17.0	34.7	9.3
		Longitudina	l at 350 F		
1L-7	48.1	47.9	24.0	68.2	8.3
1L-8	48.9	48.7	26.0	70.4	8.3
1L-9	48.2	47.8	29.0	74.3	8.0
		Transverse	at 350 F		
1T-7	44.8	43.5	18.5	50.4	8.4
1T-8	43.9	42.8	22.0	52.0	8.3
1T-9	46.1	45.0	18.0	51.6	8.6
		Longitudina	1 at 500 F		
1L-10	17.0	16.8	40.0	93.0	8.0
11-11	17.6	17.5	35.0	92.6	8.0
1L-12	18.8	18.6	39.0	93.3	6.9
		Transverse	at 500 F		
1T-10	16.5	16.2	37.0	88.0	7.2
1T~1.1	16.6	16.2	29.0	87.2	7.4
1T-12	16.2	15.9	31.0	86.8	7.4

TABLE XXVI. COMPRESSION TEST RESULTS FOR 7049-T76 EXTRUSIONS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10 ⁶ psi
	Longitudinal at Room Tempera	ture
2L-1	75.3	10.6
2L-2	81.4	11.0
23	79.6	11.1
	Transverse at Room Temperate	ire
2T-1	75.0	10.8
2'r - 2	73.0	9.9
2T-3	76.2	10.9
	Longitudinal at 250 F	
2L-4	66.4	9.5
215	71.2	10.0
2L-6	71.7	10.1
	Transverse at 250 F	
21'-4	64.0	10.4
2T 5	62.6	9.9
2T -6	63.2	10.2
	Longitudinal at 350 F	
2L-7	53.8	8.7
2L-8	53.8	9.1
2L-9	50.4	9.1
	Transverse at 350 F	
2T -7	48.8	8.9
2T-8	48.7	9.2
2T-9	49.0	9.1
	Longitudinal at 500 F	
2L-10	18.6	6.6
2L-11	19.4	6.3
2L-12	19.0	6.5
	Transverse at 500 F	
2T-10	17.6	8.0
21-11	17.8	7.4
2T-12	17.7	7.7

TABLE XXVII. SHEAR TEST RESULTS FOR 7049-T76 EXTRUSIONS

Specimen Number	Ultimate Shear Strength, ksi
Lor	ngitudinal
4L-1	45.1
4L-2	45.6
4L-3	44.6
4L-4	46.2
<u>T1</u>	cansverse
4T -1	42.6
41-2	44.9
4T-3	41.8
4T-4	41.8

THE RESIDENCE OF THE PARTY OF T

TABLE XXVIII. IMPACT TEST RESULTS FOR 7049-T76 EXTRUSIONS AT ROOM TEMPERATURE

Specimen Number	Energy ft/lbs
Longitud	inal
10L-1	6.5
10L-2	5.0
10L3	6.5
10L-4	5.0
10L-5	7.0
10L-6	4.5
Transve	rse
10T-1	1.5
10T-2	2.0
101-3	1.5
10T-4	2.0
10T-5	1.0
10T-6	1.5

TABLE XXIX, FRACTURE TOUGHNESS TEST RESULTS FOR 7049-T76 EXTRUSIONS (LONGITUDINAL)

Specimen Number	W, inches	a, inches	T, inches	Р, 1bз	Span, inches	$f(\frac{a}{w})$	ü _Q (a
6 1 ,	1.500	. 830	.750	3,440	6	3.1	47.7
5L	1.500	,848	.7 '	3,870	6	3.2	55.3
11.	1.50	. 866	.751	3.720	6	3.4	56.0
3L	1,501	.850	.750	3,850	6	3.3	55.9
2L	1,502	.859	.750	3,650	6	3.4	54.0
4L	1.500	.854	.750	3,800	6	3.3	55.8

⁽a) Candidate fracture toughness values, K_Q , are invalid as K_{Ic} values since a, T, $\frac{K_Q}{(TYS)}$.

TABLE XXX. AXIAL-LOAD FATIGUE TEST PESULTS FOR UNNOTCHED 7049-T76 EXTRUSIONS (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5 -4	65.0	9,300
5-3	60.0	68,340
5-2	55,0	86,030
5~1	50.0	177,220
5-5	45.0	7,075,410
5-6	40.0	9,717,860
	250 F	
5-17	65.0	11,950
5-19	62.5	26,240
5 -15	60.0	29,530
5-20	57.5	81,050
5-16	55.0	289,210
5-21	52.5	540,560
5-18	50.0	10,199,430 ^(a)
	350 F	
5-7	60.0	19,790
5-10	55.0	54,760
5 -8	55.0	217,850
5-12	52.5	45,110
5-11	50.0	1,457,641
5-13	47.5	400,420
5 -9	45.0	6,006,900
5-22	40.0	11,429,780 (a)

⁽a) Did not fail.

TABLE XXXI. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED ($K_t = 3.0$) 7049-T76
EXTRUSIONS (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-19	40.0	6,840
5 - 1	35.0	15,410
5-2	30.0	19,030
5 - 3	25.0	31,270
5 -4	20.0	144,750
5 -5	17.5	334,050
5-6	15.0	558,590
5-7	13.5	331 080
5 -8	10.0	15,146,300 ^(a)
	250 F	
5-16	35.0	7,640
5 -21.	32.5	9,690
5-17	30,0	20,040
5-22	27.5	23,810
5-23	25.0	19,860
5-18	25.0	934,090
5-24	20.0	841,400
5-25	10.0	843,100,
5-26	5.0	10,016,000(8)
	350 F	
5-9	35.0	9,360
5-10	30.0	20,760
5-11	25.0	19,620
5-12	20.0	84,670
5-13	15.0	159,410
5-14	10.0	652,300
5-15	5.0	10,062,800 ^(a)

⁽a) Did not fail,

TABLE XXXII. SURMARY DATA ON CREEP AND RUPTURE PROPERTIES OF 7049-176 ALUMINUM EXTRUSIONS (TRANSVERSE)

		A COLUMN										Minimum
		•		to Indic	Hours to Indicated Greep Deformation,) Deforma	ıtlon,	Initial Surain.	Rupture Time,	Elengation in 2 in.,	Reduction of Area,	Creep Rate,
Specimen No.	Stress,	e E E E E	0, i	0.2	0.5	1.0	2.0	percent	hr	percent	- 1	percent/hr
7049-31	50	250	10.2	5.0	2.7	6.4	450	0.592	20.7 580.4	\$114 LT4	43.0	0.14 0.0018
7049-36	. K	250	07		1		ł	6.459	264.3 (8.)	0.726	:	
7049-39	39	250	8	350	1670(5)		;	0.315	550,7(8)		3 3	0,60021
6	i.	936	Q C	4	v.	C*	:	0,377	5.2	15.6	68.8	0.062
70697	J	2 CS	22	52	125	200	270	0,253	337.8		17.1	0.002/
7049-35	e, n	350	245	390	1160(5)		ŀ	6.104	432,8(a)	0.333	ł	0.00042
,	1	•		,	ç	v •	r-	16 17 17	14.6	50.4	85.5	0.17
7049-37	r w	29 29	ar Pr	in's	는 무리 6 1 1시 C	. 10 5	320	0,037	124.6	40.0	73.1	0.037 0.0066
7049-310		200	٠ ٧	557	(4) 00 (2)			0.070	748.8(8)		i	0.00018
7049-31-	7.7	3	3	1	<u>.</u>							

⁽a) Test discontinued.(b) Estimate.

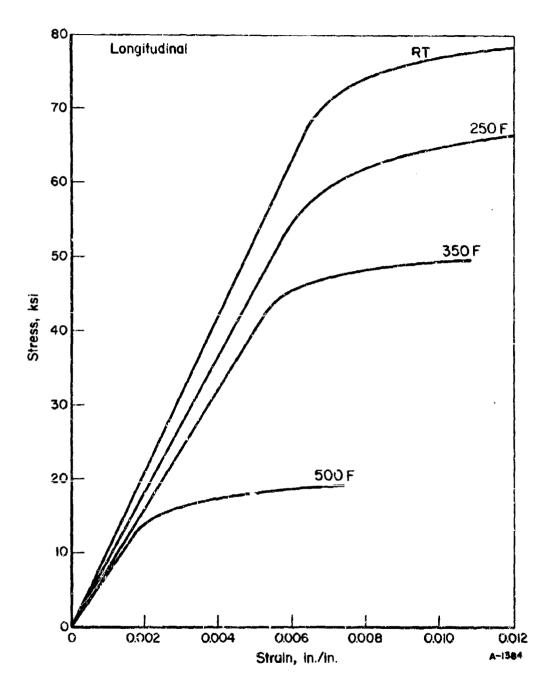


FIGURE 32. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 7049-T76 EXTRUSIONS (LONGITUDINAL)

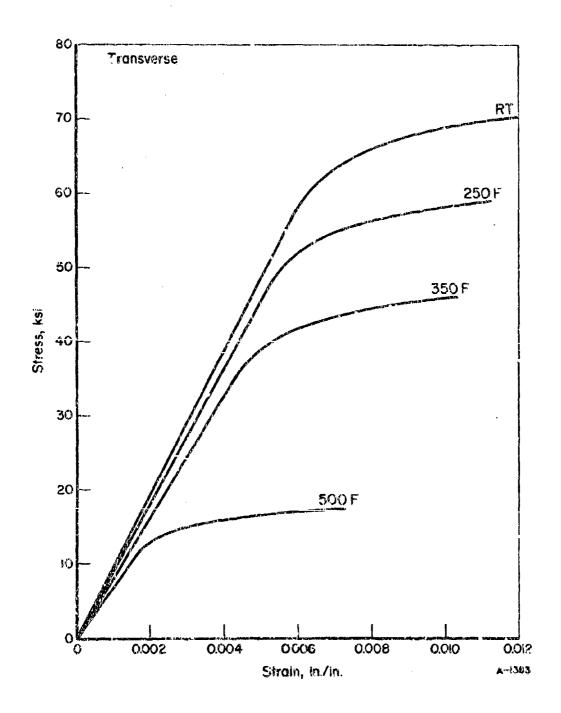


FIGURE 33. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 7049-T76 EXTRUSIONS (TRANSVERSE)

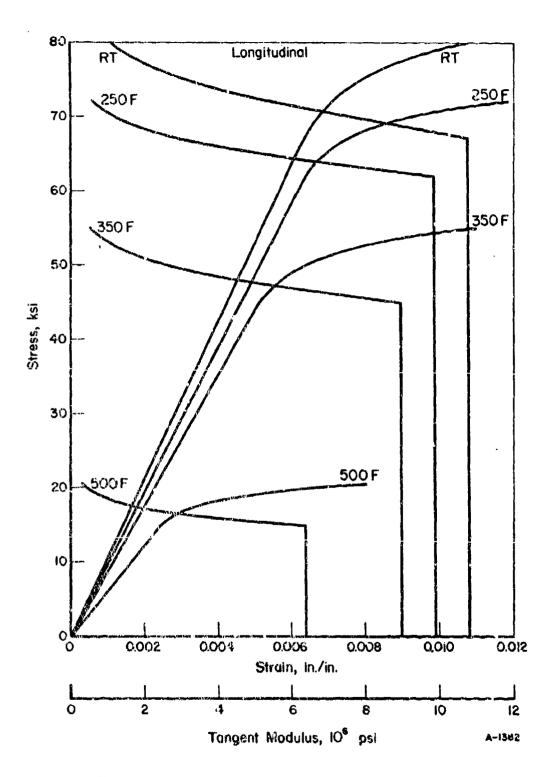


FIGURE 34. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR 7049-T76 EXTRUSION (LONGITUDINAL)

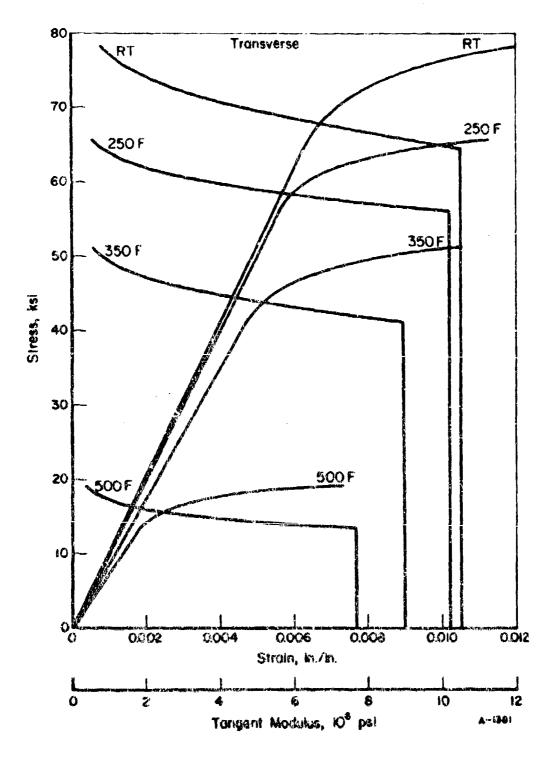


FIGURE 35. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR 7049-176 EXTRUSION (TRANSVERSE)

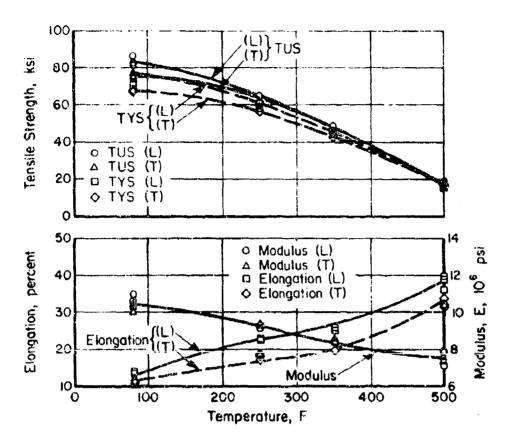


FIGURE 36. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7049-T76 EXTRUSION

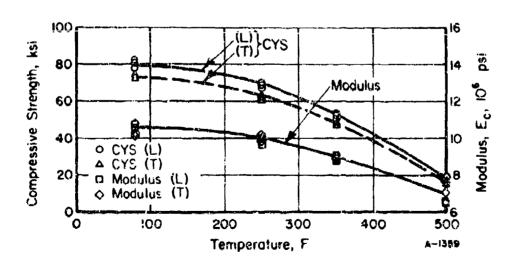


FIGURE 37. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7049-T76 EXTRUSION

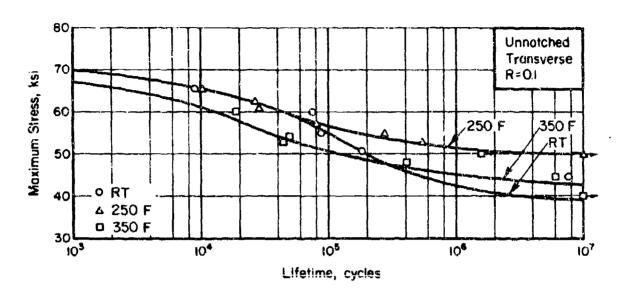


FIGURE 38. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED 70'9-T76 EXTRUSIONS

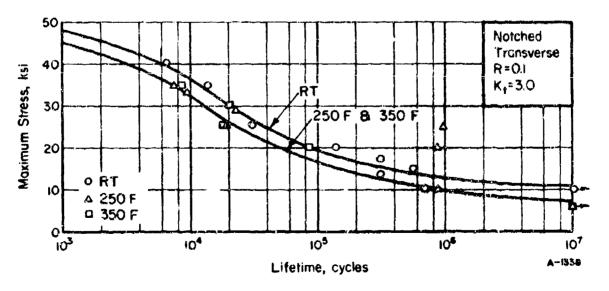
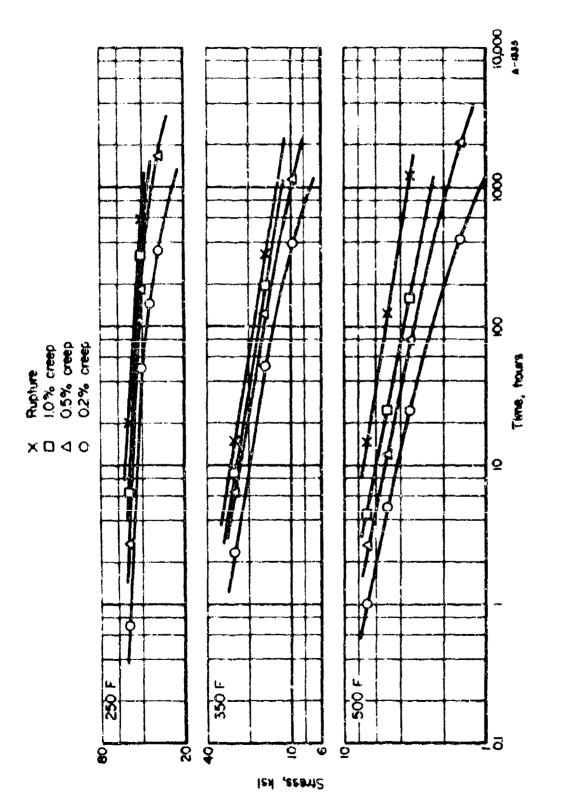


FIGURE 39. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED ($K_{\rm t} \simeq 3.0$) 7049-T76 EXTRUSIONS



STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7049-176 EXTRUSIONS (TRANSVERSE) FIGURE 40.

Ti-6Al-2Sn-4Zr-6Mo Alloy

Material Description

Initially, this alloy was developed by the Titanium Metals Corporation as an off-shoot of the Ti-6Al-2Sn-4Zr-2Mo high temperature alloy. Studies had shown that increasing the molybdenum content beyond the 2 percent level resulted in an alloy having improved room and elevated temperature strength with good creep resistance. During early development, investigations were limited to the evaluation of the alloy as a heavy section forging alloy. Premising high temperature properties achieved in heat-treated sections up to 3 inches suggested the alloy might also be useful as a sheet alloy since it should be air hardenable at sheet gages.

The material used in this evaluation was 0.075 inch sheet obtained from TMCA. It had the following composition:

Chemical	
Composition	Percent
Aluminum	5.98
Tin	1.99
Zirconium	3.94
Molybdenum	5.86
Iron	0.057
Oxygen	0.10
Nitrogen	0.004
Titanium	Balance

Processing and Heat Treating

The specimen layout for this alloy is shown in Figure 41. Specimens were machined in the as-received condition and heat-treated as follows:

- (1) 1600 F, 15 minutes, air cooled,
- (2) 1325 F, 15 minutes, air cooled,
- (3) 1100 F. 2 hours, air cooled.

This was suggested by TMCA and is called the "strengthened and heat-treated" condition.

Test Results

Tension. Results of tests in the longitudinal and transverse directions at room temperature, 400 F, 700 F, and 1000 F are given in Table XXXIII. Stress-

					•											
				F	15	473 674]		1512	ורוו	OLTI	671	97 !	471		26 +6
21.10 21.9 21.8 21.8 21.8 21.8	\$12 S14	21.2		-	Shear	411 6TE 4	+1+	e16							Te	88
5	ا ال		og			35	216 8	7								16
*			2				टाक	176								SLI
(r)		Creep	22			313										219
			8			342			971	971	971	£71	271	171	<u></u>	210
	=			Ë	····		1	<u>.</u>	1)	9TS
· · · · · · · · · · · · · · · · · · ·	E	1		E				<u>=</u>					1		—	\$15
	<u> </u>		maī.	2				9			Tensile	121			-	ETS
	타			Ē					1		۲		1			STS
ZIS	~		954				966		 	L		846	<i>ــــ</i> ــــــــــــــــــــــــــــــــ	ـــــ	-L	260
119			253				999	ļ				146				666
23	+		255 251				934					346				996
95	 		920				932	 		~		***				900
16	+		616				icc					243				888
96			BIG				930			T09		248				224
cc			418				656		W	Bito"		106				558
+ G			916	 			929	4				C+S				See
92			CIC				125	+		~		650				186
76			914 213	-			958				*	NEC			·	990

FIGURE 41. SPECIMEN LAYOUT FOR T1-6A1-2Sn-4Zr-6Mo SHEET

strain curves at temperature are presented in Figures 42 and 43. Effect-of-temperature curves are shown in Figure 46.

Compression. Test results for longitudinal and transverse specimens at room temperature, 400 F, 700 F, and 1000 F are shown in Table XXXIV. Stress-strain and tangent modulus curves at temperature are presented in Figures 44 and 45. Effect-of-temperature curves are presented in Figure 47.

Stear. Test results for single-shear sheet-type specimens tested in both the longitudinal and transverse directions at room temperature are given in Table XXXV.

Fracture Toughness. Test specimens were the full sheet thickness (0.075-inch) x 18 inch x 36 inch with an EDM flaw in the center. The 36 inch specimen dimension was parallel to longitudinal grain direction of sheets. The average K value obtained was 132 ksi $\sqrt{\text{In}}$. The net section yield stress at fracture was less than the tensile yield strength of the material. Therefore, the K value is considered valid.

Fatigue. Results of axial-load fatigue tests for transverse specimens, both unnotched and notched, at room temperature, 400 F, and 700 F are given in Tables XXXVI and XXXVII. S-N curves are presented in Figures 48 and 49.

Creep and Stress-Rup'ure. Tests were conducted at 700 F, 900 F, and 1100 F. Tabular results are given in Table XXXVIII. Log-stress versus log-time curves are presented in Figure 50.

Stress Corrosion. Testing was conducted as described in the experimental procedure section of this report. No failures or cracks occurred in the 1000 hour test duration.

The rmal Expansion. The coefficient of thermal expansion for this alloy is 5.5×10^{-6} in/in/F for 80 F to 1000 F.

Density. The density of this alloy is 0.165 lb/in3.

TABLE XXXIII. TENFILE TEST RESULTS FOR Ti-6A:-2Sn-4Zr-6Y> SHEET

	Ultimate	0.2 Percent		
	Tonsile		Elongation	
Specimen	Strength,	Strength,		
No.	ksi	kr i	percent	1.0° psi
:	Longir	udinal at Room '	Cemperature	,
11 -1	168.0	160.0	16.0	17.5
1L-2	168.0	160.0	10.0	17.7
113	168.0	160.0	11.0	17.5
	Trans	verse at Room To	emperature	
1T-1	169.0	163.0	10.6	17.2
1T-2	170.0	163.0	11.0	17.2
1T-3	169.0	163.0	14.0	17.2
	Ī	ongicudinal at	400 F	
1.14	149.0	129.0	14.5	16.4
1L-5	148.0	127.0	15.0	16.2
1L-6	148.0	127.0	15.0	16.4
		Transverse a' 4	00 F	
1T-4	150.0	130.0	14.0	15.4
1T-5	150,0	131.0	14.5	15.7
1T-6	150.0	131.0	14.0	15.9
	Ī	ongitudinal at	700 F	
1L-7	141.0	114.0	14,0	14.9
1L-8	141.0	115.0	14.0	15.4
1L9	140.0	114.0	15.5	15.0
		Tronsverse at 7	00 F	
15-7	141.0	117.0	15.0	14.7
1T-8	142.0	117.0	14.0	14.5
1T~9	143.0	117.0	14.0	14.7

TABLE XXXIII. (Concluded)

Specimen No.	Ultimate Tencila Strength, ksi	0.2 Percent Cffset Yield Strength, ksi	Llongation in 2 inches, percent	Tensile Modulus, 10 ⁸ psi
	<u>L</u>	ongitudinal at	1000 F	
1L-10	107.0	98.2	29.0	13.1
1L-11	104.0	96.0	41.0	12.6
1L-12	105.0	97.8	39.0	12.6
	•	Transverse at 1	000 F	
1T-10	1 ,6.0	98.5	35.0	12.6
1T-11	108.0	99.5	35.0	12,8
1T-12	106.0	98.8	36.0	13.0

TABLE XXXIV. COMPRESSION TEST RESULTS FOR T1-6A1-2Sn-4Zr-6Mo SHEET

	0.2 Percent	
	Offset Yield	Compression
Specimen	Strength,	Modulus,
No.	ksi	10 ⁵ pai
Longi	tudinal at Room To	emperature
2L-1	167.0	19.1
2L-2	167.0	19.6
2L-3	168.0	19.4
Tren	everse at Room Ter	nparature
2T-1	169,0	18.8
2T=2	171.0	18.9
2T-3	172.0	18.9
	Longitudinal at 4	00 F
2L-4	133.0	17.9
2L-5	133.0	17.9
2L-6	134.0	18.0
	Transverse at 40	00 F
T-4	138.0	17.5
2.12	138.0	17.8
2T-6	138.0	17.6
	Longitudinel at	700 F
2L-7	123.0	16.2
2L-8	124.0	16.4
2L-9	123.0	£6.3
	Transverse at 7	CO F
217	127.0	16,1
2T-8	127.0	16.1
21-9	126.0	16.1

TABLE XXXIV. (Concluded)

Specimen No.	G.2 Percent Offser Yield Strength, ks1	Compression Modulus, 10 ^e psi
]	ongitudinal at 1	OCO F
2L-10	110.0	13.8
2111	1.13.0	14.1
2112	199.6	13.7
	Transverse at 19	00 F
2T-10	112.0	13.4
21-11	113.0	13.7
2T~12	113.0	13.7

TABLE XXXV 3HEAR TEST RESULTS FOR Ti-6Al-2Sn-4Zr-6Mo SHEET AT ROOM TEMPERATURE

Specimen No.	Ultimate Shear Strength, ksi
<u>I</u>	ongitudinal
4L1	97.3
4L2	96.4
4L3	(a)
4 L 4	96.8
	Transverse
4 T1	(a)
4T2	98.2
4 T 3	98.1
4T4	98.0

⁽a) Did not fail in shear.

TABLE MXXVI. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED T1-6A1-23n-4Zr-6Mo SHEET (TRAISVERSE)

Specimen Number	Maximum Stress, kei	Lifetime, cycles
	Room Temperature	_
5 -7	120.0	102,620
5-1	115.0	43,920
5 - 5	112.5	1,864,250
5 - 2	110.0	59,270
5 - 4	107.5	6,079,870
5-6	105.0	495,200
5 –8	90.0	12,067,080 (a)
	400 F	
5-19	125.0	28,600
5-20	122.5	17,100
5-18	120.0	1,666,400
5 - 22	117.5	68,700
5-21	115.0	5,420, 30 0
5-23	110.0	64,300
5 - 24	100.0	573 000 ,
5-25	90.0	12,837,230 ^(a)
	700 F	
5-9	120.0	9,300
5-10	115.0	14,800
5-11	110.0	14,700
5-12	105.0	17,000
5 -13	100.0	192,200
5-17	100.0	10.796.000 ^(a)
5-10	90.0	11,032,000 ^(a)

⁽a) Did not fail.

TABLE XXXVII. AXIAL-LOAD FATIGUE TEST RESULTS FOR NOTCHED ($K_c = 3.0$) Ti-6Al-2Sn-4Zr-6Mo SHEET (TRANSVERSE)

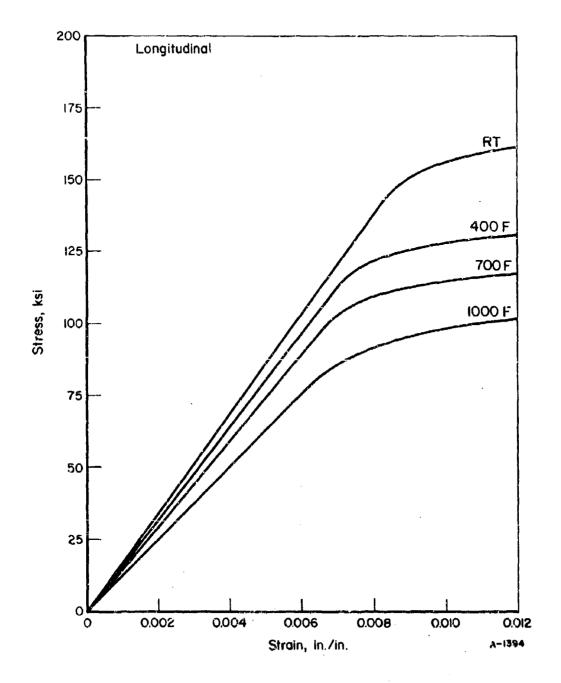
Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	ROOM TEMPERATURE	
5-1	100.0	1,130
5-2	90.0	2,510
5-3	70.0	1,510
5 -4	50.0	6,310
5-5	40.0	17,500
5 - 7	35.0	272,700 (a)
5-6	30.0	10,157,600 ^(a)
	400 F	
5 – 7	60.0	15,000
5 -8	55.0	19,000
5 - 9	50.0	19,840
5-10	45.0	27,750
5-11	40.0	43,590
5-12	35.0	10,119,850(3)
	700 F	
5-13	60,0	7,400
5-14	55.0	12,800
5-15	50.0	18,100
5-16	45.0	215,600
5-17	40.0	188,600
5-18	40.0	152,800
5-19	35.0	84,300
5-20	30.0	4,457,600
5-21	25.0	10,074,800 (a)

⁽a) Did not fail.

SUPPARY DATA ON CREEP AND RUFTURE PROPERTIES OF II-6AI-28:-42t-6Mo SHEET (TRANSVERSE) TABLE MOUIII.

0,1 0,2 0,5 1,0 2	Temper-		rs to Indi	Rours to Indicated Creep Deformation, percent	p Deformal	tion,	Initial Strain,	Rupture Time,	Elongation in 2 Inches.	Minimum Creep Rate
149 700 9 41 126 130 700 27 77 190 625 110 700 67 176 505 1126(b) 130 90 100 900 0.3 6.8 2.5 3.8 100 900 4.0 12 55 220(b) 30 900 25 95 428(b) 15 900 110 925 3900(b) 50 1100 0.06 (0.04 0.14 0.34 50 1100 0.09 0.22 0.8 1.9 50 1100 0.09 0.22 0.8 1.9 50 1100 0.09 0.22 0.8 1.9 50 1100 0.09 0.22 0.8 1.9 50 1100 0.6 1.8 8.5 17 60 1100 1.2 5.0 20 40 70 <		'	0.2	9.5	1.0	2.0	percent	hr	percent	percent/hr
135 700 27 77 190 625 120 700 67 170 505 1120 (b) 110 700 67 170 505 1120 (b) 130 900 0.3 0.8 2.5 5.8 100 900 4.0 12 55 220 (b) 30 900 25 95 428 (b) 15 900 110 925 3900 (b) 60 1100 0.06 (0.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.09 0.22 0.8 1.9 15 1100 0.09 0.22 0.8 1.9 15 1100 0.09 0.22 0.8 1.9 15 1100 0.09 0.22 0.8 1.9 15 1100 0.09 0.22 0.8 1.9 15 1100 0.09 0.22 0.8 1.9		i	:	;	:	;	;	On Loading	12.5	į
120 700 27 77 190 625 110 700 67 170 505 1120(b) 130 900 0.3 0.8 2.5 5.8 60 900 4.0 12 55 220(b) 30 900 25 95 428(b) 15 900 110 925 3900(b) 15 900 110 925 1900(b) 15 1100 0.06 10.04 0.14 0.34 35 1100 0.06 10.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17	700	£1	o n	41	126	535	8.255	624.2(8)	10.45	0.0022
110 700 67 170 505 1120 ^(b) 130 9\(\triangle^{\triangle}\) 100 900 0.3 0.8 2.5 5.8 60 900 25 95 428 ^(b) 15 900 110 925 3900 ^(b) 15 900 110 925 1900 ^(b) 15 1100 0.06 (0.04 0.14 0.34 15 1100 0.09 0.22 0.8 1.9 15 1100 0.09 0.22 0.8 1.9 15 1100 1.2 5.0 20 40	700	2.7	7.1	190	625	(q) ⁰⁰⁰ č.	2,233	672.3(4)	3,36	0, 0018
130 9°° 100 900 0.3 0.8 2.5 5.8 12 60 900 4.0 12 55 220(b) 30 900 25 95 428(b) 15 900 110 925 3900(b) 60 1100 0.06 (0.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17 3 8 1100 1.2 5.0 20 40 7	200	67	170	505	1126 ^(b)	2250 ^(b)	0.800	746.0 ^(a)	1.472	9,0008
100 900 0.3 0.8 2.5 5.8 1 60 900 4.0 12 55 220(b) 30 900 25 95 428(b) 15 900 110 925 3900(b) 60 1100 0.06 (0.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17 3 8 1100 1.2 5.0 20 40	<u>ئ</u> ۋ		:	:	:	:	7.97	0.3	17.3	;
60 900 4,0 12 55 220 ^(b) 30 900 2; 95 428 ^(b) 15 900 110 925 3900 ^(b) 60 1100 0.06 (0.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17 3 8 1100 1.2 5.0 20 40 7	906	0.3	8.0	2.5	8.0	13.0	0.769	200.6	31.5	0,062
30 900 25 95 428 (b) 15 900 111) 925 3900 (b) 50 1100 0.06 (0.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17 3 8 1100 1.2 5.0 20 40 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	8	0.4	12	55	220(b)	:	0.571	119.6(8)	1.284	0,0031
50 1100 0.06 (0.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17 3 8 1100 1.2 5.0 20 40 7	006	13	95	428(b)	;	:	0.144	143.7(8)	0.391	0.0009
60 1100 0.06 (0.04 0.14 0.34 35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17 3 8 1100 1.2 5.0 20 40 7	006	110	925	3900(b)	:	:	0,200	792.0 ^(a)	0,386	0.00016
35 1100 0.09 0.22 0.8 1.9 15 1100 0.6 1.8 8.5 17 3 8 1100 1.2 5.0 20 40 7	1100	0.06	40.0	0.14	0,34	0.67	0,569	2.3	24.9	2.5
15 1100 0.6 1.8 8,5 17 8 1100 1.2 5.0 20 40	1100	0.09	0,22	9.0	1.9	4.0	0.324	20.4	71.1	0.47
8 1100 11.2 5.0 20 40	1100	9.6	1,8	8,5	17	30	0.109	195.0	143,5	0.042
(Q) 47.5 (Q) 47.5 (Q)	1100	₹.2	5.0	8	07	75	090.0	0.006	302.0	0.022
1 1100 10 28 114 260	1100	10	28	114	260 ^(b)	:	990.0	95.4(4)	0.498	0.0035
3-14 1 1100 425 1300 ^(b) 4300 ^(b)	1100	425	1300(b)	4300(P)	;	:	0	666.4(4)	0.133	0.0001

Test discontinued. Estimate ĒĒ



r 1GURE 42. TYPICAL TENSILE STRESS-STRAIN CURVES FOR Ti-6Al-2Sn-4Zr-6Mo SHEET (LONGITUDINAL)

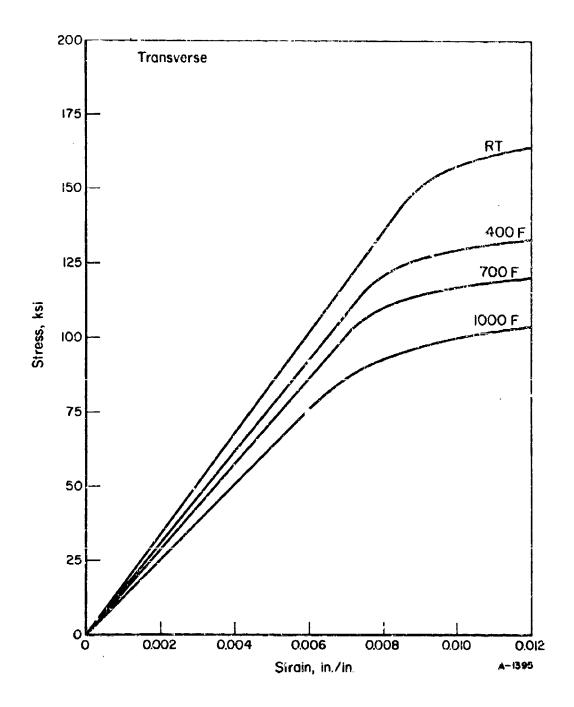


FIGURE 43. TYPICAL TENSILE STRESS-STRAIN CURVES FOR Ti-6A1-2Sn-4Zr-6Mo SHEET (TRANSVERSE)

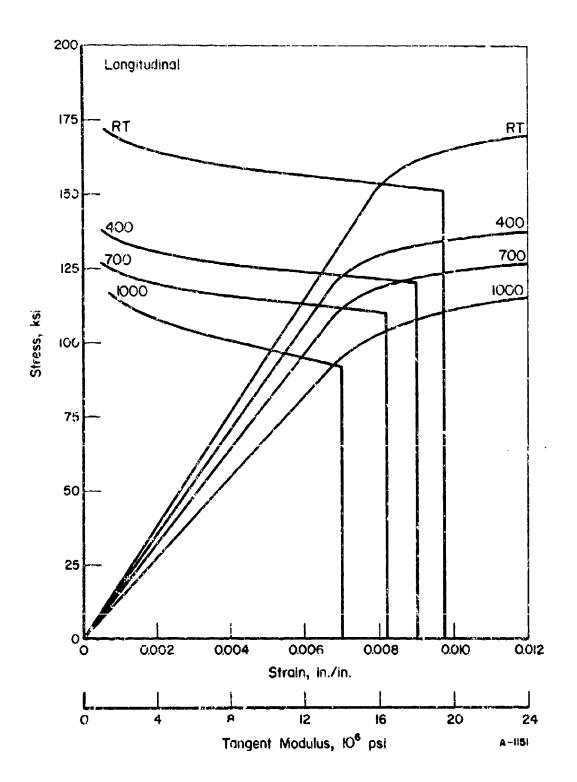


FIGURE 44. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR Ti-6A1-2Sn-4Zr-6Mo SHEET (LONGITUDINAL)

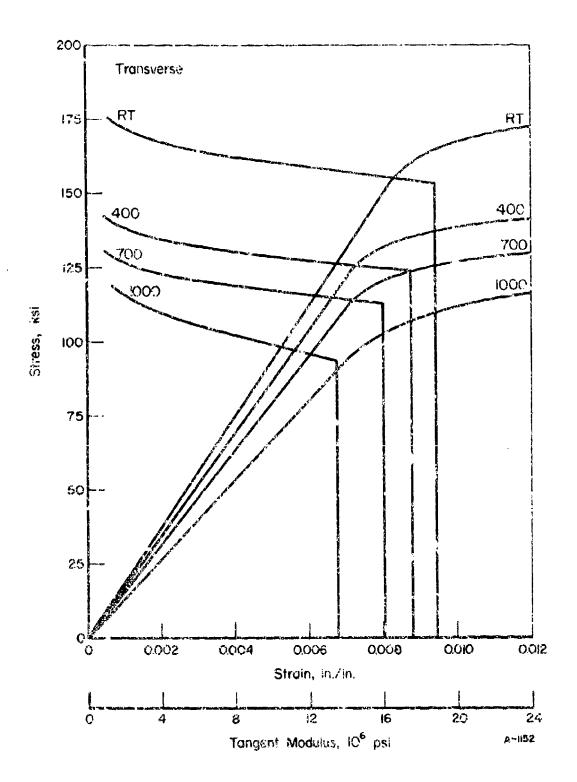
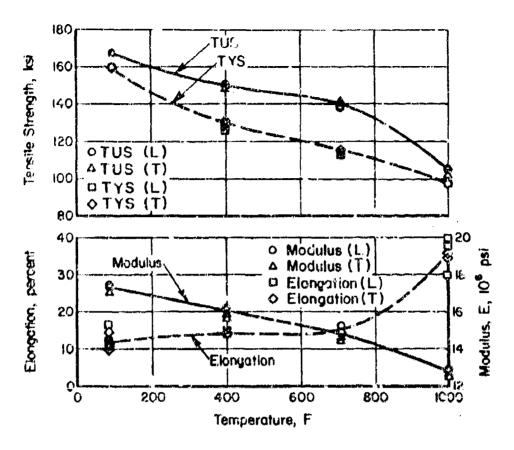


FIGURE 45. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR TI-6A1-2Sn-4Zr-6Mb SHEET (TRANSVEFSE)



国主流色型排列

FIGURE 46. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF T1-6A1-2Su-4Zr-6Mo SHEET

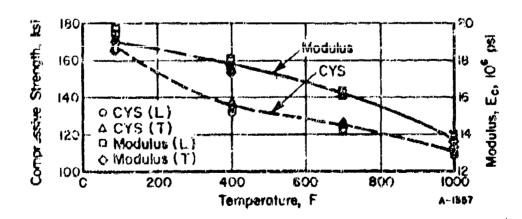


FIGURE 47. EFFEC. OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES of Ti-6A1-2En-4Zr-6Mo SHEET

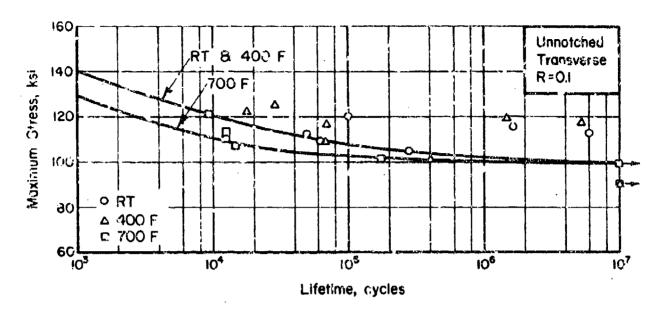


FIGURE 48. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED T1-6A1-2Sn-4Zr-6Mo SHEET

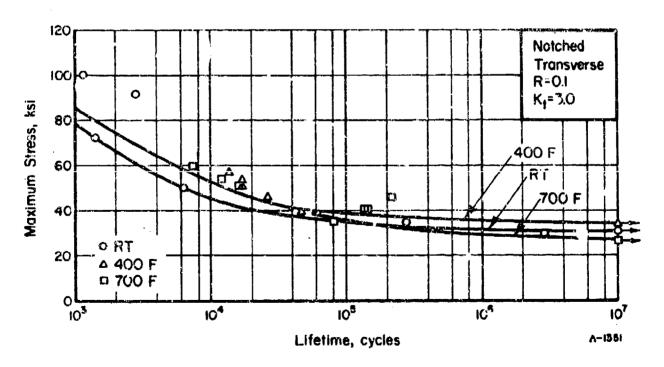


FIGURE 49. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (Kt = 3.0) Ti-6A1-2Sn-4Zr-6Mc SHEET

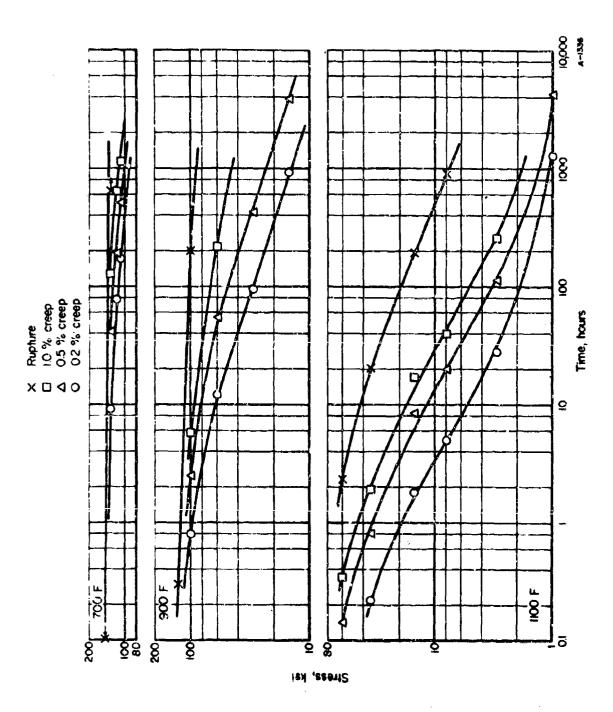


FIGURE 50. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR TI-6A1-2Sn-4Zr-6Mo SHEET (TRANSVERSE)

Inconel 702 Alloy

Material Description

Incomel alloy 702 contains high aluminum content for excellent resistance to oxidation at temperatures up to 2400 F. At elevated temperatures, the surface of a nickel-rich, nickel-chromium alloy becomes covered with a compact layer of uniformly thick oxide; the aluminum content of alloy 702 improves the protective action of the oxide. Alloy 702 has good mechanical strength at high temperatures; age hardening improves the strength of the alloy up to about 1500 F.

The material used in this evaluation was 0.050 inch sheet from Huntington Alloy Products Division, Heat HT38C3DS. The composition was as follows:

Chemical	
Composition	Percent
Carbon	0.01
Manganese	0.02
Iron	0.32
Sulfur	0.007
Silicon	0.11
Copper	0.01
Chromium	16.34
Aluminum.	3.12
Titan:.um	0.54
Nickel	79.50

Processing and Heat Treating

The specimen layout for Incomel 702 sheet is shown in Figure 51. Specimens were machined in the as-received annealed condition and then aged at 1400 F for 5 hours.

Test Results

Tension. Results of tests in longitudinal and transverse specimens at room temperature, 600 F, 1000 F, and 1400 F are given in Table XXXIX. Tensile stress-strain curves at temperature are shown in Figures 52 and 53. Effect-of-temperature curves are presented in Figure 56.

Compression. Compression test results at room temperature, 600 F, 1000 F, and 1400 F for longitudinal and transverse specimens are given in Table XL. Stress-strain and tangent modulus curves at temperature are presented in Figures 54 and 55. Effect-of-temperature curves are presented in Figure 57.

9-1376

									,																	
																									_	
																									·	
															r					,						
									16	14 [. 16				-				- 2					<u></u>		
									Ī		1				ŀ				8	4				3		
			7						4		#				}					+				25		
2112	172	20	21.9	2	2,7		818 PTS	211	. L		_}				=		 -	60013 TB:	7					*		
	Ì	121		Ì	İ		214	012	~~4 ~	ויי	175				4T3					-				<u>\$</u>		ļ
2.5	21.5	n.	2	212	ž	1 3 1		emes C	→	Ţ	ļ		3.0		7				<u> </u>	4				3		
•		î					STS	9.1	_	1	- {				1472				2	1					٠.	
		٥	لسا	Ш		L	ITS	4	2	_					Ę				F	1_				2		
						Ē					-		100		וריס	671	97 1	₹ 71	971	671	ורע] []	ורק	1 171	٦	
						€					Ē]	"	"	V , 11	"	•"	* "	• " 	' "	* "	 ` "	"	1 "		
						Ē					5			Ì							l	ł		1		ļ
			LZI			:13	,-	•:	leneT		Ę							2	١.		Ì			1		
			_			~					Ę	1						T. Age	น	Ì	ļ		ļ			
_						E						4														
						216				34	_			_		966					946				090]
		_				IK				12					_	929					140				688	- 1
						012				22	-					984					246				929	- 1
						90				51	+-		بي سي	<u> </u>		222	 -				946				- 186	-∤ i
						10			~~·	-	→~-				-	188					70				929	- 1
				_		96				*			104	•		930					2+0				+69	-
	_					99				41	9		**	04		688					19-0				223	<u> </u>
						96	. 			@ 1	-					979	<u> </u>				3+9	 -			200	-1
						55				91						189	-				220				199	4
					_	19				- P:						986	<u> </u>				920		···		014	-1
	—	_				ــــــــــــــــــــــــــــــــــــــ											<u> </u>									1

Shear. Test results for longitudinal and transverse specimens at room temperature are given in Table XL).

Fracture Toughness. Tests were conducted on specimens of full sheet thickness (0.050-inch) by 18 inches by 36 inches with EPM flaw in center. The net section yield stress at fracture was greater than the tensile yield strength of the materials; therefore, the K values are considered not valid.

Fatigue. Axial-load fatigue test results for unnotched and notched transverse specimens at room temperature, 600 F, and 1000 F are given in Tables XLII and XLIII. S-N curves are presented in Figures 58 and 59.

Creep and Stress-Rupture. Tests were conducted at 800 F, 1100 F, and 1400 F for transverse specimens. Tabular results are given in Table XLIV. Log-stress versus log-time curves are presented in Figure 60.

Stress Corrosion. Tests were conducted as described in the experimental procedure section of this report. No failures or cracks occurred in the 1000 hour test duration.

Thermal Expansion. Coefficient of thermal expansion value for this alloy is 8.7×10^{-6} in/in/F for 70 F to 1500 F.

Density. The density of this material is 0.305 lb/in3.

TABLE XXXIX. TENSILE TEST RESULTS FOR INCONEL 702 SHEET (ACED)

Specimen No.	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 inches, percent	Tensile Modulus, 10 ⁸ psi
	Longit	udinal at Room	l'emperature	
1.L-1	152.0	94.6	34.5	34.8
1L-2	153.0	94.8	3 5. 0	35.2
1L-3	153.0	94.8	35.0	33.5
	Trans	verse at Room T	emperature	
1T-1	151.0	94.5	34.0	34.4
1T-2	151.0	94.5	34 .5	33.8
1T-3	151.0	95.3	34.0	32.9
	1	Longitudinal at	600 F	
1.L-4	139,0	85.0	35.0	30.1
1L-5	139,0	86.0	38.5	29.5
1L-6	139.0	86.0	34.0	29.2
		Transverse at	600 F	
1T~4	137.0	86.3	36.0	31.6
1T-5	138.0	86.3	37.0	30.0
1T-6	138.0	86.4	37.5	31.1
	Ī	ongitudinal at	1000 F	
1L-7	131.0	85,5	36.0	28.3
1L-8	131.0	84.1	36.0	30.6
1L-9	130.0	84.0	37.0	28.8
		Transverse at 1	1000 F	
17-7	129.0	85.7	34.5	28.3
1T-8	128.0	84.9	36.0	26.9
1T-9	128.0	85.2	36.0	27.8

TABLE XXXIX . (Concluded)

Specimen No.	Ultimate Tensile Strength, ksi	0,2 Percent Offset Yield Strongth, ksi	Elongation in 2 luches, percent	Tensile Modulus, 10 ^e psi
,	Ļ	ongitudinal at	1400 F	
1L-10	66.3	63.8	8.5	19.7
1L-11	66.8	64.5	9.5	20.0
1L-12	65.4	62.4	10.0	21.0
		Transverse at 1	400 F	
1T-10	67.1	64.6	9.0	19.9
1T-11	67.5	64.9	8,5	19.6
1T-12	68.0	65.8	7.0	22.9

TABLE XL. COMPRESSION TEST RESULTS FOR INCONEL 702 SHEET (AGED)

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compressiv Modulus, psi x 10 ⁸
	Longitudinal at Room Temperature	
2L -1	99.0	34.2
2L-7	99.4	34,2
2L-3	99.8	34.8
	Transterse at Room Temperature	
2T -1	101.0	34.5
2T-2	101.0	34.5
2T-3	101.0	35.0
	Longitudinal at 600 F	
2L-4	91.0	34.5
2L ~5	91.3	34.4
2L-6	90.8	36,1
	Transverse at 600 F	
2T-4	94.4	33.0
2T -5	93.6	34.8
2T-6	92.8	32.2
	Longitudinal at 1000 F	
2L-7	90.7	31.3
2L -8	90.3	29.2
2L-9	89.6	30.0
0m 7	Transverse at 1000 F	34.3
2T -7	90.9	31.3 30.4
2T -8	90.3	30.4
2T-9	91.9	30.1
2L-10	Longitudinal at 1400 F 67.5	20.7
2L-10 2L-11	68.1	22.0
2L-11 2L-12	68.3	20.2
2L-12	00.3	20.2
2T~10	Transverse at 1400 F	20,2
2T-10	70.6	21.0
2T-11 2T-12	70.5	20.9

TABLE XLI. SHEAR TEST RESULTS FOR INCONEL 702 SHEET (AGED)

Specimen Number	Ultimate Shear Strength, kai
	Longitudinal
4L1	117.0
4L2	115.0
4L3	117.0
4L4	116.0
	Transverse
4T1	117.0
4T2	116.0
4T3	113.0
4T4	117.0

TABLE XLII. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED INCONEL 702 SHEET (AGED) (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5 -4	75.0	98,300
5-3	65.0	209,900
5-2	55.0	591,700
5 –1	45.0	1,594,800
5-8	40.0	7,086,400
5-5	35.0	3,403,100
5 – 7	30. 0	10.138.000
5 – 6	25.0	10,130,000 ^(a)
	600 F	
5-11	75.0	117,500
5-12	65.0	184,400
5-13	55.0	584,200
5 - 14	45,0	4,809,000 10,226,700(8)
5-16	40.0	10.220.700
5 - 15	35.0	12,376,900 ^(a)
	1000 F	
5-21	75.0	12,400
5 - 22	65.0	245,300
5-23	65.0	536,200
5-26	60.0	5,428,800
5 - 24	55.0	4,337,200
5-25	50.0	10.097.700 (4)
5 - 27	45.0	10,331,300 ^(a)

⁽a) Did not fail.

TABLE XLIII. A XIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K = 3.0) INCONEL 702 SHEET (AGED) (TRÂNSVERSE)

Specimen Number	Meximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5 _4	65.0	31,900
5-3	55.0	111,100
5-2	45.0	336,200
5-7	40.0	782,400
5 - 8	40.0	1,651,000
5-1	35.0	1,511,600
5-6	30.0	636 000
5-5	25.0	10,537,500 ^(a)
	600 F	
5-13	65.0	15,700
5-11	55.0	75,300
5-15	50.0	821,200
5~12	45.0	250,400
5-24	42.5	6,248,000
5 - 25	40.0	
5-16	37 <i>.</i> 5	3,672,800 24,268,000(a)
5-14	35.0	10,069,500 ^(a)
	1000 F	
5-21	65.0	12,900
5-22	55.0	51,500
5-27	50.0	719,200
5 - 23	45.0	1,274,800
5 -3 5	40.0	7,917,100
5-34	35.0	10,549,600 ^(a)

⁽a) Did not fail.

TABLE FLIT, STAMMET DATA ON CREEP AND RUPTURE PROPERTIES OF INCOMEL 702 SHRET (AGED) (TRANSVERSE)

		Tomber-	Rouri	to Indic	Moure to Indicated Greep Deformation,	De format:	ton,	Intei#1	Rupture	Elongetion	Creep
Specimen	Strees	ature,			percent	Š		Strein,	Time,	17 / 1n.,	nercent /hr
Newber	ksi	5 4	9.1	0.2	0.5	7.0	2.0	4	nr	per cent.	11/21/21
3-13	132	ROG	;	;	!	:	:	:	On Loading	38.7	:
3-10	000	8	i	i	;	:	:	;	486.0(4)	ŧ	:
3-1	120	25	12	20		1250(h)	!	14,520	764.7(8)	15.24	0.0057
3-11	120	9 68	20	. 280	1150(b)		i	9.204	290.0(a)	9.406	0.0003
3-14	100	609	:	. 1	į	:	:	4.618	194.5(8)	4.647	:
e.,	ec	1108	· ¥•0	. 1.5	Ś	12.8	28	0.442	38.1	4.4	0.063
. e7	75	1100	۴.	20	38	25	;	0.269	105.2	3.1	0.010
47 47		1100	2	43	131	220	:	0.316	262.7	2.0	0.003
න	36	1100	2	323	835	1125	ł	0.198	1165.0	1.8	0.0004
e.	90	1400	9.0	5.7	rð rð	:	;	0.164	15.0	3.1	0.053
4	7 7	3400	4.0	12.0	30	4	;	0.135	63.1	3.1	0.013
94	11	1433	11	84	124	198	255	0.067	261.9	3.1	0.0038
3-3	12	1400	9	140	313	485	550	0.051	884.8	13.3	0.001
3-12	vo	1400	435	655	1100 G)	:	; 1	0.018	642.5(4	0.211	0,0001

⁽a) Test discontinued.
(b) Estimate.

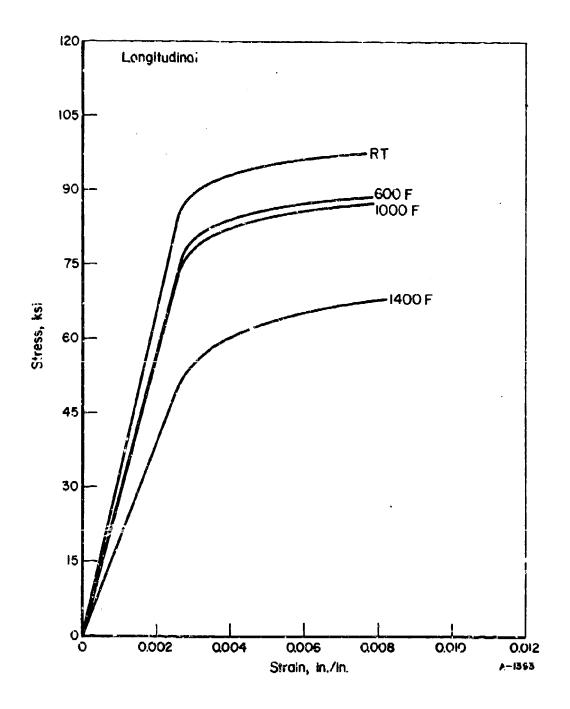


FIGURE 52. TYPICAL TENSILE STRESS-STRAIN CURVES FOR INCONEL 702 SHEET (AGEL) (LONGITUDINAL)

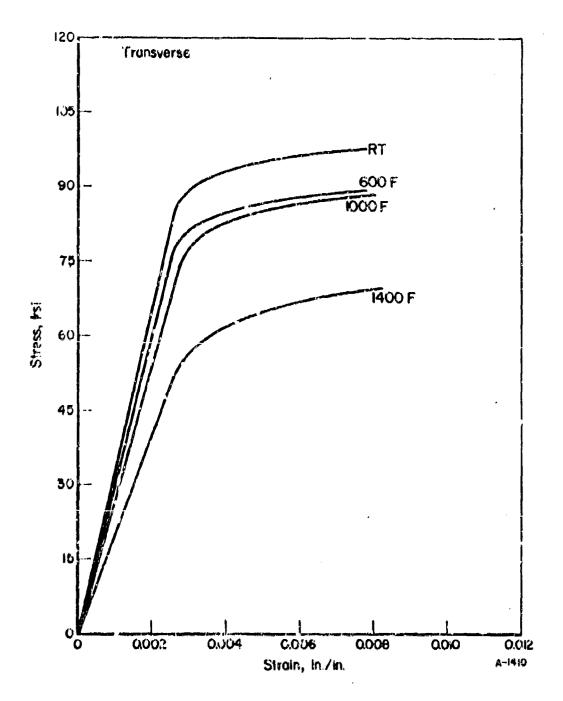


FIGURE 53. TYPICAL TENSILE STRESS-STRAIN CURVES FOR INCOMEL 702 SHEET (AGED) (TRANSVERSE)

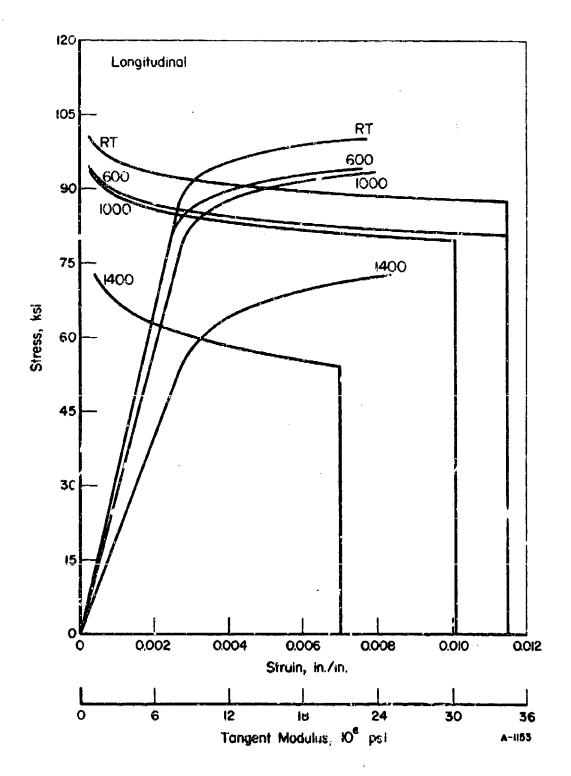


FIGURE 54. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR INCOMEL 702 SHEET (AGED) (LONGITUDINAL)

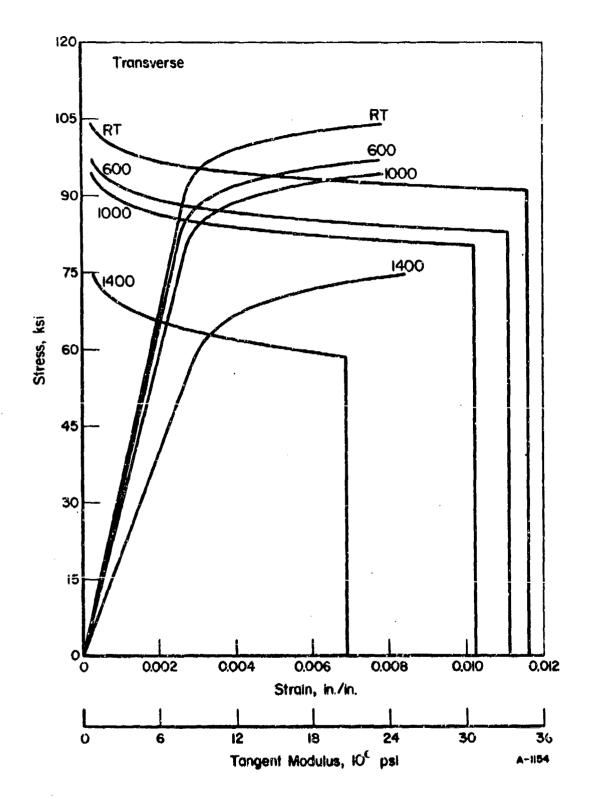


FIGURE 55. TYPICAL COMPTASSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR INCONEL 702 SHEET (AGED) (TRANSVERSE)

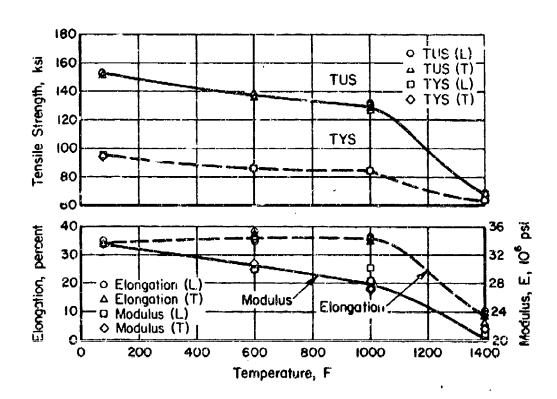


FIGURE 56. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF INCONEL 702 SHEET (AGED)

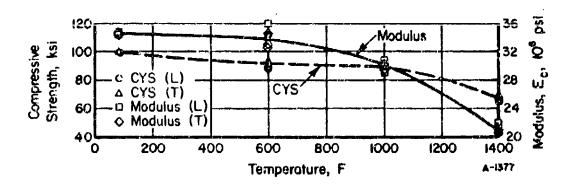


FIGURE 57. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF INCONEL 702 SHEET (AGED)

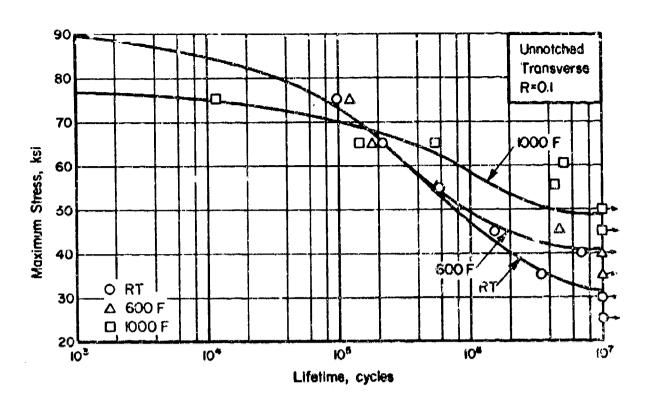


FIGURE 58. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED INCONEL 702 SHEET (AGED)

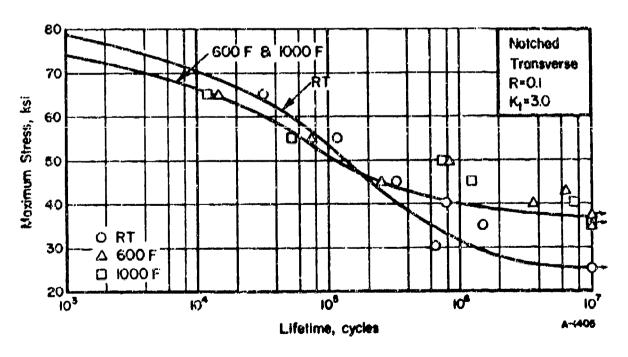
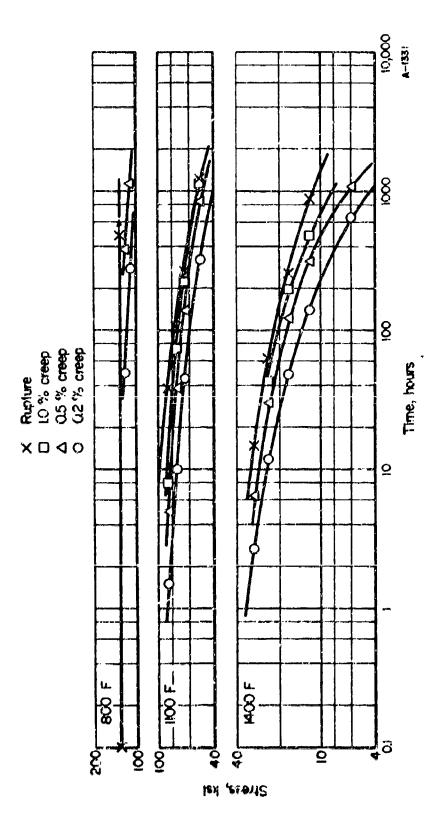


FIGURE 59. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K = 3.0) INCONEL 702 SHEET (AGED)



これのはできる ちゅうけい かしゅうちゅう おもらない あばればい いちかい 間のない ないない はない はない ないない はんしゅう しんしゅう かんしゅう

STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR INCOMEL 702 SHEET (AGED) (TRANSVERSE) FIGURE 60.

Inconel 706 Alloy

Material Description

Incomel alloy 706 is a precipitation-hardenable, nickel-iron-chromium alloy with characteristics similar to those of Incomel 718, except that 706 has improved machinability. It has high strength at temperatures ranging from cryogenic to 1300 F. It also has good resistance to oxidation and corrolion over a broad range of temperatures and environments.

Fabrication of the alloy is enhanced by its good formability and weldability. Alloy 706 has excellent resistance to postweld strain-age cracking.

The material used in this evaluation was obtained as a 6-inch-square forging from INCO, Heat HT50C3HK. The composition was as follows:

Chemical	
Composition	Percent
Carbon	0.03
Mangenese	0.12
Iron	36.37
Sulfur	0.007
Silicon	0.13
Copper	0.02
Chromium	16.32
Aluminum	0.28
Titanium	1.62
Columbium plus	
Tantalum .	2.96
Nickel	42.12

Processing and Heat Treating

The 6-inch-square material was press forged to a 2 inch x 6 inch bar to make specimen blanks easier to obtain. The specimen layout is shown in Figure 61. After machining, specimens were heat treated as follows for optimum creep-rupture strength:

- (1) 1800 F, 2 hours, air cool,
- (2) 1550 F. 3 hours, air cool,
- (3) 1325 F, 8 hours, furnace cool to 1150 F, hold for 18 hours, air cool.

Test Results

Tension. Results of longitudinal and transverse tests at room temperature, 800 \overline{F} , $\overline{1000}$ F, and 1200 F are given in Table XLV. Stress-strain curves at

								, (5 0	٤ ،	9 #1	. 0	01	g Zı	•	91	. OS	20	i 65	91	. 09	51	121 12 12 12 12 12 12 12 12 12 12 12 12	novaneT &	121				Tension 12 L	11.6	11.621.5 21.627.2 21.627.6 11.621.7 72.12.2 21.2 27.13.11.10.2 21.10.2	21.5 21.5 72.2.5 73.2.5	21.5 21.5 21.0 21.0 21.0 21.0 21.0 21.0 21.0 21.0	2 K 121	21.6 21.6272 274 276 21.0 273 274 276
29	25	₩9	96	6/2	BIG	ri G	916	1.0	28	25	25	58	22	22	EG	EG EG			4	⊸				ic .	Ģ	×s		rida o	-		<u> </u>	=		112	11122111	2	2LIZZTB ZTGZTZ		RT R
	*	1850ax		ē	1			3	L L	}	S		ā		, , , , , , , , , , , , , , , , , , ,) a.			ı																				
	PR		*********************	5	ا عنا	Pacity Co.	\ _p	1			٤-9			7																									
	13	101	X	2			į	8	3		ધ્ર		23			İ						-	ž	÷	1	1	Cul Specimen Blanks Two Deep As Shown	Ž	4 C	Shoet Shoet							4	9-1366	

FIGURE 61. SPECIMEN LAYOUT FOR INCONEL 706 FORGED BAR

temperature are shown in Figures 62 and 63. Effect-of-temperature curves are shown in Figure 66.

Compression. Results of longitudinal and transverse tests at room temperature, 800 F, 1000 F, and 1200 F are given in Table XLVI. Strass-strain and tangent-modulus curves at temperature are shown in Figures 64 and 65. Effect-of-temperature curves are presented in Figure 67.

Shear. Pin shear test results for longitudinal and transverse specimens al room temperature are given in Table KLVII.

Impact. Charpy test results for room temperature longitudinal and transverse specimens are given in Table XLVIII.

Fracture Toughness. Results of slow bend tests at room temperature are given in Table XLIX. The size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, therefore the K_Q value in the table is not a valid K_{TC} value by existing ASTM criteria.

Fatigue. Axial-load fatigue tests were performed on transverse specimens, both notched and unnotched, at room temperature, 600 F, and 1000 F. Test results are given in Tables L and LL. S-N curves are presented in Figures 68 and 69.

Creep and Stress-Rupture. Tests were conducted at 800 F, 1000 F, and 1200 F. Results are given in Table LII. Log-stress versus log-time curves are presented in Figure 70.

Stress Corrosion. No failures or cracks occurred in the 1000 hour test duration as described in the experimental procedure section of this report.

Thermal Expansion. The coefficient of thermal expansion for Incomel 706 is 9.8×10^{-6} in/in/F for 70 F to 1500 F.

Density. The density of this material is 0.291 1b/in3.

TABLE XLV. TENSILE TEST RESULTS FOR INCONEL 70% FORGED LAR (STRISS-RUFTURE HEAT TREATMENT)

Specimen Number	Ultimate Tensila Strength, ksi	0.2 percent Offset Yield Strongth, Lsi	Elongation in 2 inches, percent	Reduction in Area, percent	Tensile Modulus 10 ⁸ psi
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	Lo	ngitudinal at Ro	on Temperature		
1L-1	177.0	138.3	22.0	32.5	30.9
1L-2	178.0	139.0	22.5	33.5	28.9
1L-3	178.0	139.0	23.0	32.5	27.9
	3	ransverse at Roo	m Temperature		
1T-1	176.5	146.0	21.5	30.0	29,7
1T-2	176.0	140.0	22.0	31.5	28.6
1T-3	176.0	140.0	22.5	31.5	31.6
•		Longitudiual	at 800 F		
1L-4	157.0	120.0	22.0	37.0	24.3
115	155.0	120.0	21.0	39.0	23.9
115 116	157.0	122.0	23.0	36.5	24,4
		Transverse	at 800 P		
1 T -4	138.0	121.0	21.0	36.5	24.8
17-4 17-5	15/.0	122.0	29.5	33.5	25.9
15-6	15 .0	123.0	19.0	34.3	23,3
		Longitudinal	at 1000 P		
1L-7	152.0	119.0	20.0	38.0	22.1
1L-8	152.0	120.0	20.5	40.0	20.4
1L-9	151.0	119.0	22.5	40.5	21.2
,		Trensverso	at 1000 T		
11-7	152.0	120.0	19.0	33.5	22.0
17-8	153.0	121.0	19.5	35.5	21.2
17-9	154.0	122.0	18.0	35.0	21.3
		Longitudinal	at 1200 F		
1L-10	139.0	117.0	25.0	39.5	21.4
1L-11	138.0	. 116.0	25.5	40.5	21.4
1L-12	138.0	115.0	26.0	41.5	20.3
		Transversa	1200 F		
17-10	139.0	116.0	23.0	40.0	20.1
17-11	139.0	117.0	24.0	36.0	20.
1T-12	139.0	118.0	21.5	37.5	20.9

TABLE XLVI. COMPRESSION TEST RESULTS FOR INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

	0.2 Percent	
	Offset Yield	•
Specimen	Strength,	Modulus,
No.	ksi	10 ⁶ pai
Longitu	dinal at Room Tem	perature
2L-1	149.0	31,8
2L-2	150.0	30,9
2L-3	150.0	30.6
Transv	erse at Room Temp	erature
2T-1	149.0	30.8
2T-2	149.0	31.1
2T-3	149.0	32.4
Lo	ngitudinal at 800	F
2L-4	127.0	23.9
2L-5	124.0	25.2
2L-6	129.0	23.7
<u>T</u>	ransverse at 800	<u>F</u>
2T -4	129.0	24.6
2T -5	131.0	24.0
2T-6	128.0	23.9
<u>L</u> .o	itudinal at 100	0 F
2L-7	123.0	23.2
21,-8	123.0	23.0
2L-9	124.0	22.8
<u>T</u>	ransverse at 1000	<u>F</u>
2T -7	125.0	24.5
2T-8	125.0	23.4
2T-9	124.0	24.0

TABLE XLYL (Concluded)

Specimen No.	0.2 Percent Offset Yield Strength, ksi	Compression Needulus, 10° pst
ī	ongitudinal at 120	00 F
2L-10	118.0	23.3
2L-11	120.0	22.0
2L-12	122.0	22.1
	Transverse at 1205) <u>F</u>
2T-10	120.0	23.2
2T-11	120.0	22.2
2T-12	124.0	22.2

TABLE MINIM. SHEAR TEST RESULTS FOR INCOMEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

THE THE PERSON AND THE PARTY OF THE PARTY.	THE REAL PROPERTY AND ADDRESS.
Ultimate Shes Strength, ks	Spacimen Number
ongitudinel	Lo
117.0	411
117.0	4L -2
117.0	4, -3
118,0	4114
Tyung verse	
117.0	4T-1
117.0	41-2
117.0	45-3
117.3	4T-4)

TABLE XLVIII. IMPACT TEST RESULTS FOR INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

Specimen Number	Energy, ft/lbs
Longiti	idinal
1011	29,5
10L-2	32.0
1013	33.9
1014	31.5
10L-5	33.0
10h-6	32.0
Trans	verse
10T-J.	2à.0
10T-2	26.0
10T-3	28.0
10T-4	26.5
10T~5	25.0
1(T -6	27.0

TABLE XLIX. FRACTURE TOUCHNESS TEST RESULTS FOR INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

fptciman Number	W, Inch a e	a, inchas	l. inch ss	P, 1bs	Span, inches	f (₩)	K _Q (a
			Longitud	inal			
11	1.498	.73 7	.750	9,800	4.5	2.6	83.3
27.	1.499	.754	.751	9,900	4.5	2.5	86.9
3 L	1.500	.760	.750	10,250	4.5	2.7	91.1
			Transve	rse			
1 T	1.497	. 747	.750	10,150	4.5	2.6	88.3
27	1,490	.749	.747	9,850	4,5	2.6	84.3
37	1.497	.735	.749	10,750	4.5	2.6	91.3

⁽a) Condidate fracture toughness values, K_Q , are invalid as K_{Tc} values since a, $T_c < 2.5 \, \left(\frac{K_Q}{\rm qrg}\right)^2$.

TABLE L. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED INCONEL 706 FORGED BAR (STRESS-RUFTURE HEAT TREATMENT) (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	L'fetime, cycles
	Room Temperatu	re
5-3	125.0	88,100
5-4	115.0	150,300
5 -2	105.0	227,500
5-1	95.0	364,400
5-5	85.0	679,000
5.6	75.0	2,199,400
5-7	65.0	8,446,000
5-8	60.0	10,025,200 ^{(a}
	600 F	
5-17	125.0	25 , 220
5-16	115.0	42,700
5-19	105.0	82,100
5-20	95.0	139,900
5-2 l	85.0	164,300
5-22	75.0	422,300
5-23	65.0	6,226,100
524	55,^	10,792,700 (a
	1000 F	
5-9	125.0	14,006
5-10	115.0	42,700
5-11	105.0	31,300
5-12	95.0	163,600
5-13	85.0	165,300
5 -14	75.0	722,303
5-15	65.9	2,232,100
5-16	55.0	5,557,700
5-25	45.0	12,239,200 (1

⁽e) bid not fail.

TABLE LI. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (Kt = 3.0) INCONEL 706 FORGED HAR (STRESS-RUPTURE HEAT TREATMENT) (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperatur	e
5-1	105.0	9,900
5-2	9 5.0	14,100
53	85.0	32,000
5-4	75.0	29,000
55	65.0	47,200
5-6	55.0	88,300
57	45.0	150,000
5-8	35.0	445,900
5-23	30.0	475,000
3 ∼9	25.C	4,770,490
5-10	20.0	11,953,000 ^(a)
	600 F	
5-11	75.0	25,300
5-12	65.0	44,900
5.43	55.0	74,000
5-14	√5.0	204,700
5 - 25	40.0	255,100
5-15	35.0	529,500
5-26	30.0	10,012,000(0)
5-16	25.0	13,091,900 ^(a)
	1000 F	
5-17	75.0	12,200
5-18	65.0	25,700
5-19	55.0	46,900
5-20	45.0	116,300
5 -2/	40.0	17,555,700 ^(a)
5.21	35.0	7.421.600
5-22	30.0	11,685,000 ^(a)

⁽⁸⁾ Did not fail.

SUPERARY DATA ON CHEEP AND RUPTURE PROPERTIES FOR INCONEL 705 FORCED BAR (STRESS-RUPTURE HEAT TREATHENT) (TRANSVERSE) TABLE LII.

			1	•		Sac Same		104746	Profestra	Elonestion	Reduction	Creep
Spec (Rea		Tero.	Routs to	_	ndicated treep pergrature.	3410134 1	,,,,,	Strata,	Time,	to 2 in.,	of Area,	Rate,
¥o.	ks1.		0.1	0.2	0.3	ਹ ੰ.℃	2.0	percent	hr	percent	percenc	percentum
	93.	2					0 0	11 E	On Loading	16.9	34.7	:
77 (136	₹ 6 0		(a) ye.				14,345	476,8(4)	14.520	1	0.00010
7	155	2	2	7		}		2	186 5(4)	6 610	;	:
9-10	051	0	*	8 3 £		fi =	į	, c			,	
4	;	Ş	4	3	, C	06 0	6	12,288	en en	11.5	34.7	3.1
m M	2		3 3 3 4	} . > .	។ ទីពួ	3	90	3.41	263.3	9,2	13.2	0.014
, 9 9)	14 C	25	") -> a	4 6	- C	S	(4)0081	1.625	743.8(4)	2.580	:	0.001
4 op m 10)	25	3 3	\$30 0	(4),0067		3 :		0,839	791.2(4)	0.962	:	0.00001
•	•		4	•		F-1	7.7	0.681	20.4	6.1	20.4	0.22
n d	130) (D	9	31.5	20.	2	967.0	140.0	13.9	22.1	0.011
, 49 1	8		88		1000(b)	•	1	0.550	719.5(4)	0.816	6	0.0028

(a) Test discontinued.(b) Estimate.

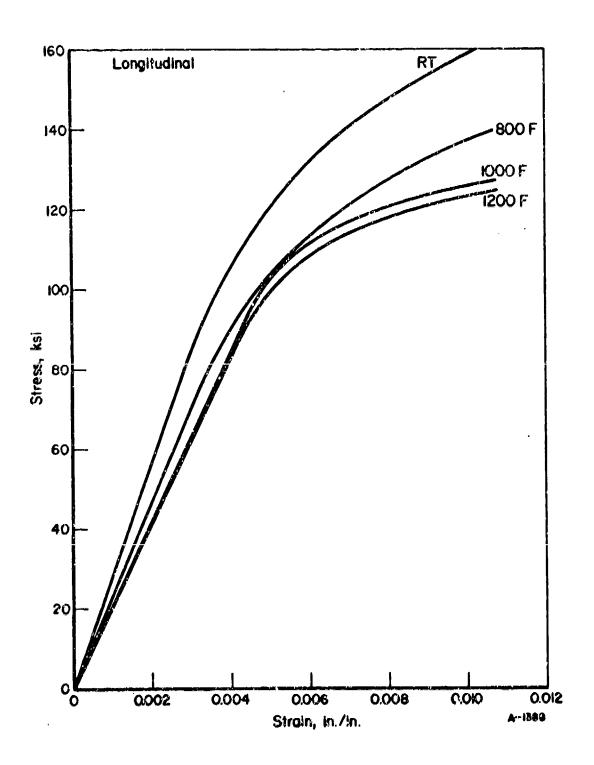


FIGURE 62. TYPICAL TENSILE STRESS-STRAIN CURVES FOR INCONEL 706 FORGED BAR (LONGITUDINAL) (STRESS-RUPTURE HEAT TREATMENT)

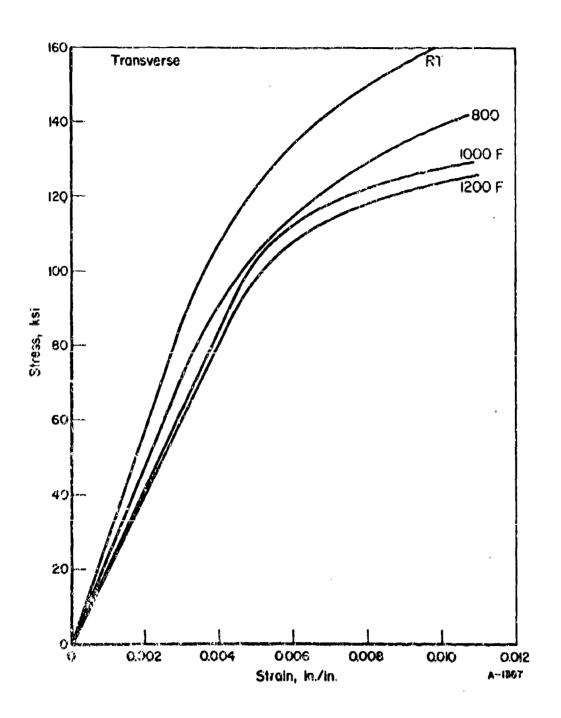


FIGURE 63. TYPICAL TENSILE STRESS-STRAIN CURVES FOR INCOMEL 706 FORGED BAR (TRANSVERSE) (STRESS-RUPTURE HEAT TREATMENT)

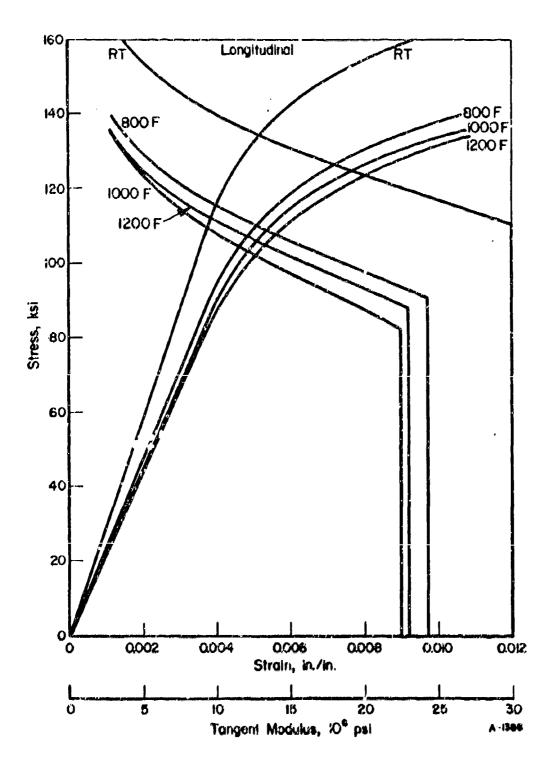
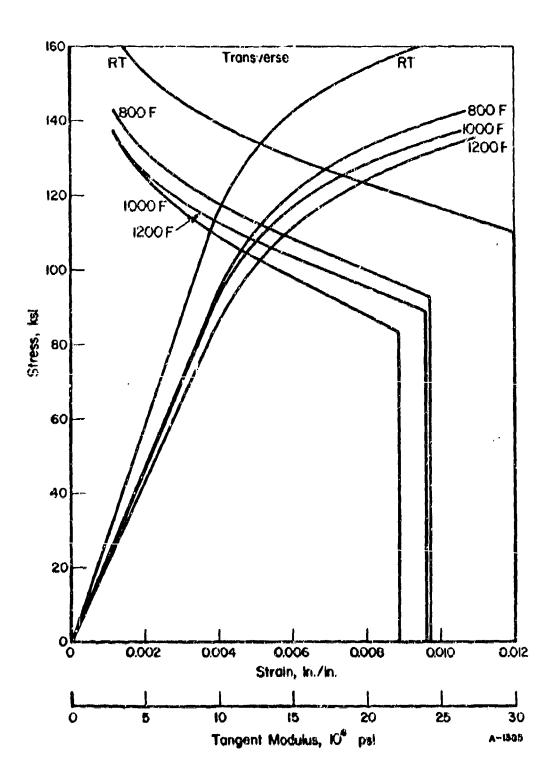


FIGURE 64. TYPICAL COMPRESSIVE STRESS-STRAIN AND TARGENT-MODULUS CURVES FOR INCONEL 706 FORGED BAR (LONGITUDINAL) (STRESS-RUPTURE HEAT TREATMENT)



The second secon

FIGURE 65. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR INCONEL 706 PORGED BAR (TRANSVERSE)
(STRESS-RUPTURE HEAT TREATMENT)

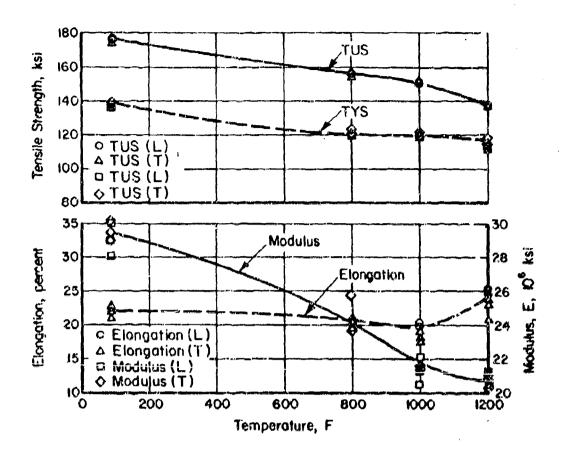


FIGURE 66. EFFECT OF TEMPERATURE ON THE TEMBILE PROPERTIES OF INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

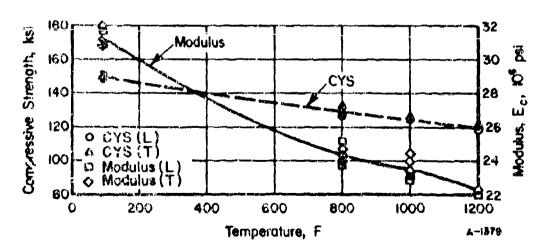


FIGURE 67. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

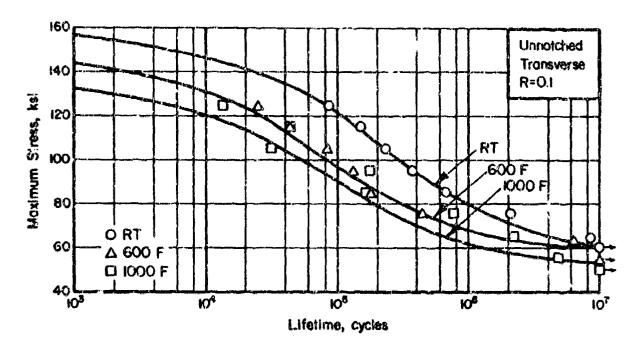


FIGURE 68. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

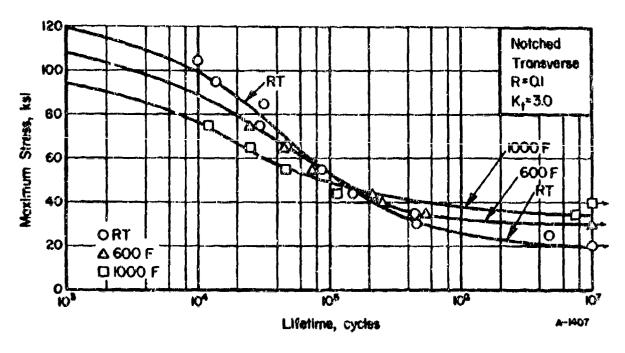
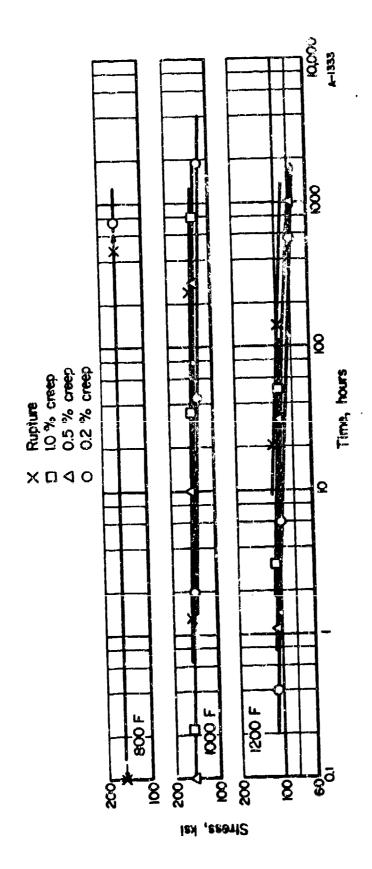


FIGURE 69. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K = 3.0) INCOMEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)



STRESS-RUPTURE AND PLASTIC DEPORMATION CURVES FOR INCOMED 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT) (TRANSVERSE) PICURE 70.

The state of the s

DISCUSSION OF PROGRAM RESULTS

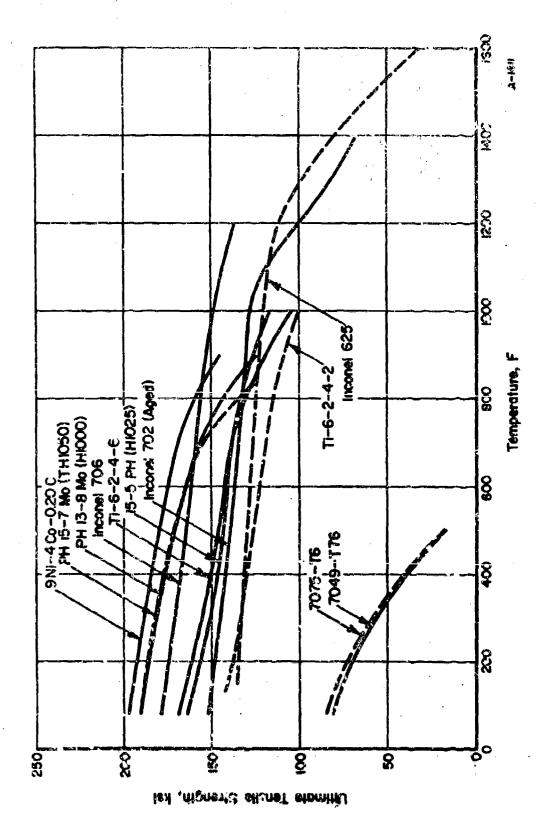
The tendency in an evaluation program of this type is to compare the materials property information obtained with similar data on materials already in use. Whether such a comparison should be the deciding factor for interest in a newer alloy is open to question. Many criteria, such as forming characteristics, weldability, oxidation resistance, etc., can be of particular importance so that strength properties may become secondary. However, since first comparisons are almost always made on the basis of mechanical strength (tensile ultimate and tensile yield) the data generated on this program are compared to information for similar alloys in Figures 71 and 72.

CONCLUSIONS

The objective of this program was the generation of useful engineering data for newly developed materials. During the contract term the following alloys were evaluated:

- (1) 15-5 PH (H1025) stainless steel forged bar
- (2) HP 9Ni-4Co-0.20C steel forged bar
- (3) PH 13-8 Mo (H1000) stainless steel forged bar
- (4) 7049-T76 aluminum extrusion
- (5) 6Al-2Sn-4Zr-6Mo titanium sheet
- (6) Incomel Alloy 702 sheet (Aged)
- (7) Income! Alloy 706 forged bar (Creep-rupture heat treatment).

A data sheet was issued for each material. As a summary, each of the data sheets is reproduced in Appendix III.



PIGURE 71. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPPATURE

では、100mmので

THE RESERVE THE PROPERTY OF THE PARTY OF THE

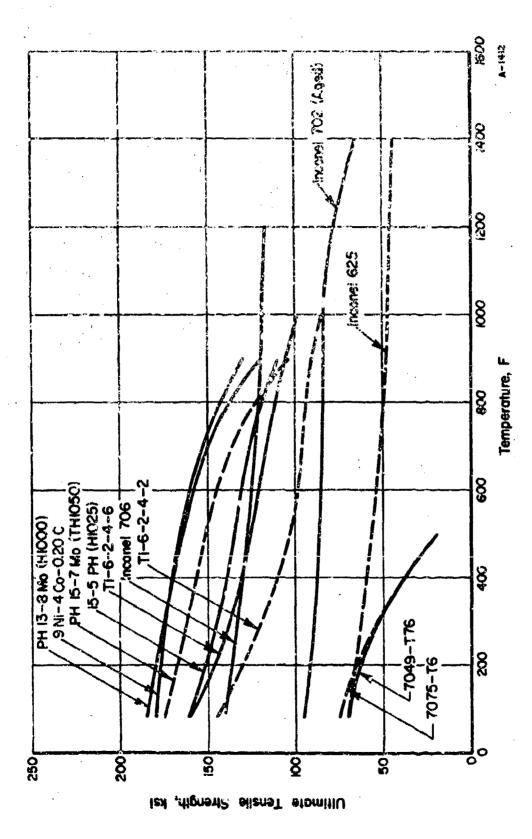


FIGURE 72. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE

APPENDIX I

EXPERIMENTAL PROCEDURE

APPENDIX I

EXPERIMENTAL PROCEDURE

Mechanical Properties

The various mechanical properties of interest for each of the materials are as follows:

- (1) Tension
 - (a) Tensile ultimate strength, TUS
 - (b) Tensile yield strength, TYS
 - (c) Elongation, e
 - (d) Reduction in area, RA
 - (e) Modulus of elasticity, E,.
- (2) Compression
 - (a) Compressive yield strength, CYS
 - (b) Modulus of elasticity, Ec.
- (3) Creep and stress-rupture
 - (a) Stress for 0.2 or 0.5 percent deformation in 100 hours and 1000 hours
 - (b) Stress for rupture in 100 hours and 1000 hours.
- (4) Shear
 - (a) Shear ultimate strength, SUS
- (5) Axial fatigue*
 - (a) Unnotched, R = 0.1, lifetime: 10^3 through 10^7 cycles

[&]quot;R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. " K_t " represents the Neuber-Peterson theoretical stress concentration factor.

- (b) Notched $(K_c = 3.0)$, R = 0.1, lifetime: 10^3 through 10^7 cycles.
- (6) Fracture toughness, K_{Ic} or K_c
- (7) Stress corrosion
 - (a) 80 percent TYS for 1000 hours maximum, 3-1/2 percent NaCl solution.
- (8) Thermal expansion.
- (9) Bend
 - (a) Minimum radius.
- (10) Impact
 - (a) Charpy V-notch.
- (11) Density.

Specimen Identification

A simple system of numbers and letters was used for specimen identification. Coding consisted of a number indicating the type of test and also indicating a comparable area on the sheet, plate, or forging. For certain test types, the number was followed by a letter signifying specimen orientation (L for longitudinal, T for transverse, ST for short transverse). The test types where the letter did not appear were creep, fatigue, and bend since, in these cases, only one specimen orientation was used. The next number in the coding specifies the location from which the specimen blank was taken from the original material configuration. Coding was as follows:

Assigned Number	Test Type
1	Tension
2	Compression
3	Creep and stress-rupture
4	Shear
5	Fatigue
6	Fracture toughness

Assigned Number	Test Type
7	Stress corrosion
8	Thermal expansion
9	Bend
10	Impact
11	Density

As an example, a specimen numbered 2-T5 is a compression specimen, transverse orientation, cut from Location 5. Also, a specimen numbered 5-12 is a fatigue specimen cut from Location 12.

Test Description

Tension

Procedures used for tension testing are those recommended in ASTM methods E8-68 and E21-66T as well as in Federal Test Method standard No. 151a (method 211.1). Six specimens (three longitudinal and three transverse) were tested at each temperature to determine ultimate tensile strength, 0.2 percent offset yield atrength, elongation, and reduction in area. The modulus of elasticity was obtained from load-strain curves plotted by an autographic recorder during each test.

All tensile tests were carried out in Baldwin Universal testing machines. These machines are calibrated at frequent intervals in accordance with ASTM method E4-64 to assure loading accuracy within 0.2 percent. The machines are equipped with integral automatic strain pacers and autographic strain recorders.

Specimens tested at elevated temperatures were heated in standard wire-wound resistance-type furnaces. Each furnace was equipped with a Foxboro controller capable of maintaining the test temperature to within 5 F of the control temperature over a 2-inch gage length. Chromel-Alumel thermocouples attached to the specimen gage section were used to monitor temperatures. Each specimen was soaked at temperature at least 20 minutes before being tented.

An averaging-type linear differential transformer extensemeter was used to measure strain. Per elevated temperature testing, the extensemeter was equipped with extensions to bring the transformer unit out of the furnace. The extensemeter conformed to Ai M E3-64T Classification B1 having a sensitivity of 0.0001 inch/inch. The strain rate in the elastic region was maintained at 0.005 inch/inch/minute. After yielding occurred, the head speed was increased to 0.1 inch/inch/minute until fracture.

Compression

Procedures for conducting compression tests are outlined in ASTM Method E9-67 along with temperature control provisions of E21-66T. All sheet and thin plate tests were carried out in Baldwin Universal testing machines using a North American type compression fixture as shown in Reference 2. Specimen heating was accomplished by a forced-air furnace for temperatures up to 1000 F. Specimen temperature was maintained by means of a Wheelco pyrometer. Three Chromel-Alumel thermocouples attached to the fixture were used to monitor temperatures to within 3 F of the test temperature. For highe: temperatures, wire-wound furnaces were used with controls as described in the tensile test section.

The extensometer used for the compression tests was quite similar to that used in the tensile testing. The extension arms were fastened to the specimen at small notches spanning a 2-inch gage length. The output from the microformer was fed into a load-strain recorder to provide autographic load-strain curves. During testing the strain rate was adjusted to 0.005 inch/inch/minute.

For bar and forging material, cylindrical specimens similar to those described in ASTM E9-67 were used with appropriate temperature control and strain measurement as described above.

Six specimens (three longitudinal and three transverse) were tested at each temperature.

Shear

Single-shear sheet-type specimens were used for sheet and thin-plate material; for ber and forgings, a double-shear pin-type was used. Shear testing was performed at room temperature only. A manimum of six specimens (three longitudinal and three transverse) were used to determine ultimate shear strength.

Bend

The procedures for conducting bend tests are described in Report MAB-192-M. The specimens were placed in a rigid three-point loading finture and bending tups of various sizes were used to determine the minimum bend radius at room temperature.

Creep and Stress Rupture

Standard dead-weight type creep testing frames were used for the creep and stress-rupture tests. These machines are calibrated to operate well within the accuracy requirements of ASTM method E139-66T.

Specimens similar to those used for tension tests were used for the creep and stress-rupture studies. A platinum strip "slide rule" extensometer is attached for measuring creep strain and three Chromel-Alumel thermoccuples are attached to the gage section for temperature measurements. Extensometer measurements were made visually through windows in the furnace by means of a filar micrometer microscope in which the smallest division equals 0.00005 inch.

The furnace was of conventional Chromel A wire-wound design with taps along the side to allow for correcting small temperature differences. Furnace temperature was maintained to within \pm 2 F by Foxboro controllers in response to signals from the centrally located thermocouple. The temperature of a specimen under test was stabilized for at least 1/2 hour prior to loading.

For each temperature condition creep and stress-rupture data were obtained to 100 and 1000 hours using as many specimens as necessary to obtain precise information. The percent creep deformation obtained was dependent on the material under test. In most instances stress-time curves were defined for 0.2 and 0.5 percent elongation.

Stress Corresion

Seven specimens of each alloy were tested for susceptibility to stress-corrosion cracking by alternate immersion in 3-1/2 percent sodium chloride solution at montemperature.

Specimens were prepared for testing by degreasing with acetone. Where a surface film remained from heat treating, it was abraded off one side and the adjacent long edge of five of the specimens, and left intact on the other two.

Each specimen was placed in a four-point loading fixture and deflected to a stress corresponding to 80 percent of the tensile yield strength of the particular wateriol. The specimen was electrically insulated from the fixture by means of glass or sapphire rods. Defisction for a given maximum fiber stress was colculated by the following expression:

$$y = \frac{\sigma(3L^2 - 4a^2)}{12dE}$$

where

y = deflection

o = maximum fiber stress

1 = distance between outer load points

a - distance between outer and inner load points

d = specimen thickness

E = modulus of specimen material.

Each stressed specimen was suspended on an alternate immersion unit. This unit alternately immersed specimens in the 3.5 percent sodium chloride solution for ten minutes and held them above the solution to dry for 50 minutes. Tests were continued to the first sign of cracking or for 1000 hours, whichever occurred first.

Specimens were given frequent low-power microscopic examinations to detect cracks. At the first sign of cracking the specimen was removed. At the conclusion of the test, selected samples were sectioned and examined metal-lographically for any indication of cracking. Representative samples in which cracks were found were also given a metallographic examination to establish the type and extent of the cracks.

Thermal Expansion

Linear-thermal-expansion measurements were performed in a recording dilatometer with specimens protected by a vacuum of about 2 x 10⁻⁶ mm of mercury. In this apparatus a sheet-type specimen is supported between two graphite structures inside a tantalum-tube heater element. On heating, the differential movement of the two structures caused by specimen expansion results in the displacement of the core of a linear-variable differential transformer. The output of the transformer is recorded continuously as a function of specimen temperature. The entire assembly is enclosed in a vacuum chamber.

The furnace is controlled to heat at the desired rate, usually 5 F per minute. Errors associated with measurements in this apparatus are estimated not to exceed + 2 percent. This is based on calibration with materials of known thermal-expansion characteristics.

Fatigue

Fatigue tests were conducted using MTS electrohydraulic-servocontrolled testing machines. The frequency of cycling of these machines is variable to beyond 2,000 cpm depending on specimen rigidity. These machines operate with closed-loop deflection, strain or load control. Under load control used in this program, cyclic loads were automatically maintained (regardless of the required amount of ram travel) by means of load-cell feedback signals. The calibration and alignment of each machine are checked periodically. In each case, the dynamic load-control accuracy is better than + 3 percent of the test load.

For elevated temperature studies, an induction heating coil controlled by a Lepel Induction Heater was used. A thermocouple placed on the center of the specimen controlled temperature to + 5 degrees.

After machining and heat treating (when required), the edges of all sheet and plate specimens were polished according to Battelle-Columbus' standard practice prior to testing. The unantched specimens were held against a rotating drum covered with emery paper and polished using a kerosene lubricant. Successively finer grits of emery paper were used, as required, to produce a surface

of about 10 RMS. Unnotched round specimens were polished in the Battelle-Columbus polishing apparatus. This machine utilizes a rotating belt sander driven rectilinearly along the specimen test section while the specimen is being rotated. The belt speed and specimen speed are adjusted so that polishing marks on the specimen are in the longitudinal direction. The surface finish is about the same as that on the flat specimens. The notched flat specimens were held in a fixture and polished with a slurry of oil and alundum grit applied liberally to a rotating wire. Notched round specimens are polished in the same manner, except that the specimen is rotated.

A shadowgraph optical comparator was used for measuring the test sections of all polished specimens and for inspection of the root radius in the case of the notched specimens.

The stress ratio for all specimens was R = 0.1. Stresses for notched $(K_t = 3.0)$ and unnotched specimens were selected so that S-N curves were defined between 10^3 and 10^7 cycles using approximately 10 specimens for each set of fatigue conditions.

Fracture Toughness

Two types of fracture toughness tests were used. For heavy section materials, the chevron-notched, slow bend test specimen of ASTM Method E-399-72 was selected. For thinger section sheet materials, center through-cracked tension panels were used as test specimens. All specimens were precracked in fatigue and subsequently fractured in a servocontrolled electrohydraulic testing system of appropriate load capacity.

The slow-bend type specimens were precracked and tested under 3-point loading. The pop-in load for materials susceptible to brittle fracture was determined from the load-compliance curve. When pop-in was not detectable, the curves were analyzed using the 5 percent secant offset method of the ASTM procedure.

The thin sheet center through-crack tension panels were initially sawcut and then precracked in constant amplitude fatigue loading. In order to maintain a flat fatigue crack and not plastically strain the uncracked section, the maximum stresses were adjusted to keep the applied stress-intensity factor less than one-third or one-quarter of that anticipated at fracture. This usually involved stepping down the stresses as the cracking proceeded. The crack was extended to approximately one-quarter of the panel width. Buckling guides were attached and a clip-type compliance gage was mounted in the central notch. The panels were fractured in a rising load test at a stress rate in the range

which corresponds nominally to the gross strain rate of standard tensile testing.

APPENDIX II SPECIMEN DRAWINGS

٧...

こうこと これにはいいかと 物質は大きな変なのないのがあいませんない

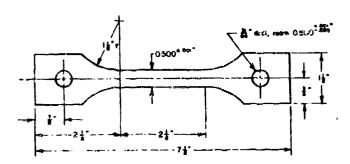


FIGURE 73. SHEET AND THIN-PLATE TENSILE SPECIMEN

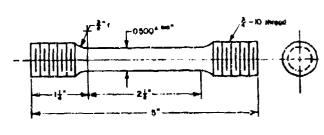
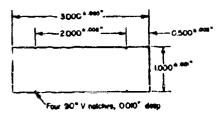


FIGURE 74. ROUND TENSILE SPECIMEN

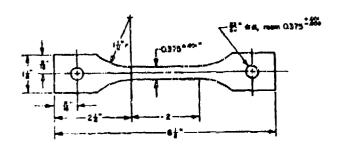


Notes I. Ends smet be fiel and perallel to within 0.0002", 2 Surface must be from from ricks and acrotches.

Ends to be that and par to within 00002" of C

FIGURE 76. ROUND COMPRESSION SPECIMEN

FIGURE 75. SHEET COMPRESSION SPECIMEN



RUPTURE SPECIMEN

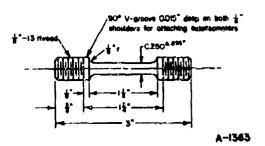


FIGURE 77 . SHEET CREEP - AND STRESS - FIGURE 78. ROUND CREEP - AND STRESS -RUPTURE SPECIMEN

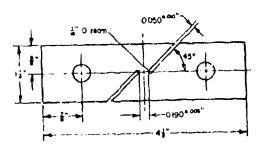


FIGURE 79. SHEET SHEAR TEST SPECIMEN



FIGURE 80. PIN SHEAR SPECIMEN

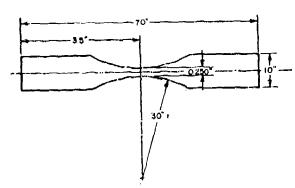


FIGURE 81. UNNOTCHED SHEET FATIGUE SPECIMEN

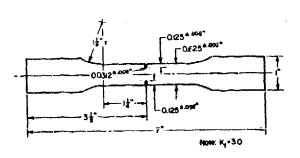


FIGURE 82. NOTCHED SHEET FATIGUE SPECIMEN

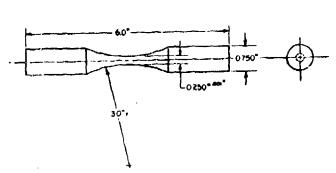


FIGURE 83. UNNOTCHED ROUND FATIGUE SPECIMEN

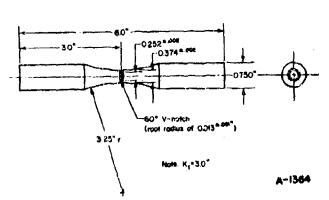


FIGURE 84. NOTCHED ROUND FATIGUE SPECIMEN

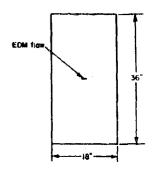


FIGURE 85. SHEET FRACTURE TOUGH-NESS SPECIMEN

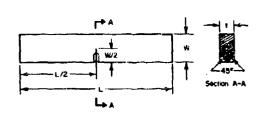


FIGURE 86. SLOW BEND FRACTURE TOUCHNESS SPECIMEN

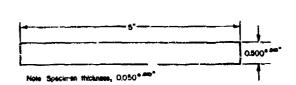


FIGURE 87. STRESS-CORROSION SPECIMEN

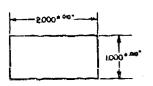


FIGURE 88. THERMAL-EXPANSION SPECIMEN

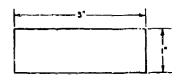


FIGURE 89. SHEET BEND SPECIMEN

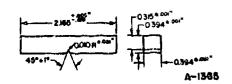


FIGURE 90. NOTCHED IMPACT SPECIMEN

APPENDIX III

DATA SHEETS

15-5 78 Stelulese Steel

15-5 PR is a precipitation-hardening stainless steel that offers a combination of high strength and hardens, excellent corrosion resistance plas good transverse toughness and good forgashility. It is produced by concumable vacuum are remaining and it virtually "farrite fred".

Petrication practices for 19-5 FR are generally the same as those satablished for 17-4 PR. Most techniques are similar to those recommended for the regular grades of stainless steel. Mardening heat treatments require temperatures of only 900 F to 1150 F, depending on the properties desired. Recesse of the comparatively low hardening temperatures scaling and distortion difficulties are ensentially pluminated.

19-5 PR to eveilable in the form of billate, plate, har, and wire. Syminal applications include forgings, pump and valve parts for high presours systems, afteraft components, and hollow har parts for hydroniale actuators and controls.

The chamical composition of the forging used for this evaluation is

es follows:

Przest	.037	£.	910.	010.	ę.	13.14	4.50	3.32	Ą	é	Balence
Chartes! Composition	Carbon	Menganase	Phosphorus	Sulfac	Silcon	Chromium	Mickel	Copper	Columbium	Tentelm	Iron

The material tested was obtained from Armeo Heat 4440370 in the form of 2-1/8 inch x 5-3/4 inch x B foot formed but.

Proceeding and Book Treating

Speciment were mathined in the as-received Condition, ϵ followed by beat treatment for 4 hours at 1023 T to Condition £1023.

15-5 PM Steinless Steel Data (e)

Condition: H 1025 Thickness: 2 Inch x 6 inch forged bar

			3	
Properties	RT	007	400 705	ğ
Unelon				
Sed (Leading to the Control of the C	164.3	147.0	137.3	119.3
TOS (YOURTHOUTHER) MAI	0.49	146.7	136.0	118.6
('cc ('mayaras')	167.6	140.3	128.3	111.0
	161.6	140.3	127.0	110.0
(Transvers),	15.3	12.2	10.6	14.7
(Inditionally), percent		10.7	9.2	13.8
(transverse), percent in c	2 5	9	7	8
(legipaliteor)	3 2	t 5	3	7
(transverse), percen		•	22.0	22.2
E (longitudinal), lumper E (transverse), los pei	28.8	28.2	25.1	23.2
Checkellon				
Cyte (lone(endine)), had	163.6	144.6	130.0	111.6
(LTA DE WETRE)	165.3	0.44	130.0	111.0
(lengitudine	30.2	28.8	27.7	7.4.
, E	30.3	, 28. 9	29.1.	ž
(a) Theat				
	2.80	9_	Þ	þ
508 (transverse), kai	104.3	•	Þ	p
(p) (input (q)			•	•,
Wanted Charge, ft. 1b. (longitudinal)	80.7	Þ	PI	1
ft. 1b.	40.7	Þ	Þ	:
Practure Tourbass				
E. trafata	3	Þ	=	>
76.				
dais! Patigue (transverse)				
eri eri	•	771	97.	t
104 cycles, bai	77	3 2	13	, p
i i	133	110	110	9
cycles, tot	142	230	ព្	D
:	7 (25	1	• •
10' cycles, ksi	2	3	۱	۰

I'ms to Statishess Stant Switz (continued)

			trace, 7		
Berg C. Cambon .	u	3	ž.	ж 11	
STATE OF THE PERSON NAMED IN COLUMN					
Commission of the state of the	# a	ខ្លួច	8. Ç	13 ec	
Served transfer (1)					
Decree 155 lb., bat	44	98	**	អ្ន	
Acres Carraigo					
57, 175, 1000 to machine	n cracks				

Configuration of Participation

6.7 x 10 ta/ta/7 (70 to 9007)

Meter

0.263 Befin

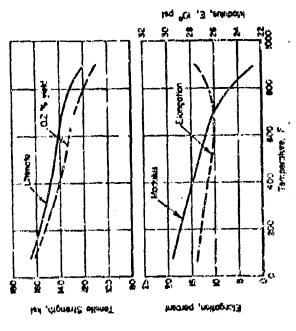
- (a) Values are everage of triplicate tests confected at lattello maint via (a)) self-contract mites arbertle fadistid. Jather, they, and about maint of high the tract mites arbertle fadistid. The resident maint of high
- (b) Double-absert pin-type open was anorthe of A chots.
- H. smaretlable; 34, not applicable.

Ē

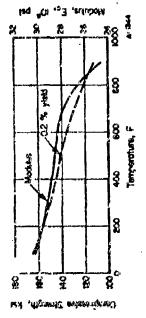
- (d) Average of 5 thetts.
- (a) Six longitudinal alow-band specimens were reacted. Specimen also was 0.130-5045.

 thick by 1.500 (school wide with a spin of 5 varies. The servage N poblation was 131.0 Auglf 7 (2012).

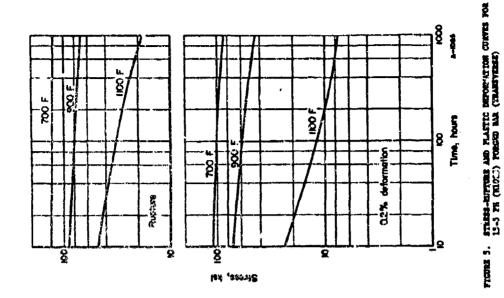
 131.0 Auglf 7 (2012) the also meter, 2.5 (Aprilly), was prestar this both this speciment that the same cash is leafth in all takes, did a Nq value in 202 o wide N₁₈ when by sectoring will servate.
 - (f) "W" represents the algebraic retic of months stress to markets bracket is now spale; the talk to be a second to be a secon
- (g) Becomparations there-solat bank onet. Abundan impresses in 3 173 Each.

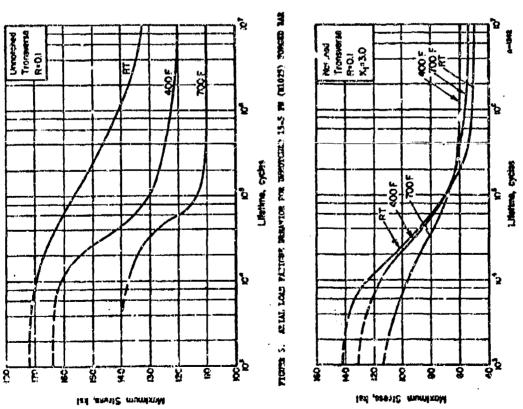


FIGST 1. EFFOT OF THEORYTHE OF THE FEBSILE PROTECTES OF U.S. PS (MINES) PORCED MR.



PICES 2, EFFET OF TEMPERATURE OF THE CONTRACTOR PARCED PAR





Material Description

MP 9R1-4Co-0.20C steel was developed specifically to have high hardenshifty combined with good fracture temphase. It can be welded in the fully bear-treated credition and achieve secentially 100 periont joint efficienty without probast or posthest treatment. The O-30C grade is available as abset, strik, plate, bers, forgines, and tubing.

The material used for this program was consumable cleatrods vacuum meltad and from Republic Steel Beat 3821033. It was obtained as a 2-1/4 inch x 6. inch Ketped bar and had the following etupoolaiem:

Percent	0.19 0.56 0.00	9.99 9.98 9.98	3.3.8 3.3.8	4.70 Palance
Composition	Carbre Manganese Pleaspherse	Sulfer #2166 Hebsi	Chronica Nolyberson General	Cotale

Precessing and Back Areacist

Spectmens were rough machined in the as-received assealed condition, bear treated so follows:

- (1) mermalise at 1650 P, 1 hour, atr-cool,
- (2) sectualities or 1900 F, 1 heur, oil quenth,
- (3) single temper at 1025 F, 6 bours, ein ovel and thom finish machined.

119 MELAGOLO 200 DOSA 911

Condition: Quenched and Tempered Thickness: 2 inch x 6 inch forging

		Tennerati	76. 6	
Properties	THE STATE OF	\$00		8
Terefor				
Tit (leastinging), had	197.0	179.7	170.3	147.6
(transverse). ha		129.0	168.6	147.0
(innettudinal)	180.6	165.0	155.3	129.6
(transverse).	180.0	186.0	152.7	119.0
_	17.5	16.0	16.2	18.0
percent in 2	14.6	14.0	14.5	16.0
(longtochal), mercent	9	65.5	66.7	69.8
MA (transverse), sercent	26.0	55.5	57.8	3 4.
Clone i Eudige	27.0	26.0	24.3	22.0
E (transverse), IC pei	27.3	23.9	24.7	23.8
Compression				
CTS (loneitudinal), kai	196.7	171.6	159.0	135.3
(transverse), he	17.6	171.3	158.0	135.6
(longitudinal)	27.4	26.4	23.1	¥.¥
(transverse), 10 p	2.0	7.9	25.3	S.
Shear (0)		•		
and Alexandered bases of the same	7 2	(c)	=	\$2
(transcerse). In	12	, p	. .	, ; >
These E'C'	•			
Venotch Charac ft. 31b.				
(longituling)	3	Þ	9	P
(transverse)	53	D	5	Þ
Irecture Touchoses				
	•	1	;	1
K. (longitudinal), kei/la. K. (ersamaras), kei/la.	3 3	9 0	5 13	;
Je ()				
Arial Patione (trespures)(#)				
	•			
TO COLUMN NATIONAL PROF	170	170	170	Þ
and a	2	101	121	Þ
cyelst,	ŝ	*	115	Þ
				٠
Motenhad, 7, w.5.0, M. w.0.1.	7.1	114	717	†
	: :	:		,
in cycles, El	3 :	3	23	Þ
	X	ደ	2	Þ

HP STI -ACO-D. 200 Data (continued)

・ 100mm 10

		Tumperati	, au	
Propert Son	##	556 70	%	20
Crosp (transverse)				
0.22 plastic deferenting, 100 hr. had	1	3	113	8
0.13 plantic defermetion, 2000 hr, bal	#	149	æ	ដ
Stress Supture (framswerps)				
Bapture, 160 hr, haf	4 ;	29.	121	20.5
Mappens, 1950 or, Mos.	í	ŝ	A BT	2
Bereas Correston				
40% TYS, 2600 hr martines.	ne areachs			
Coefficient of Themas Expansion				

4.6 x 10" ts./la./7 (80 to 990 7)

Theme

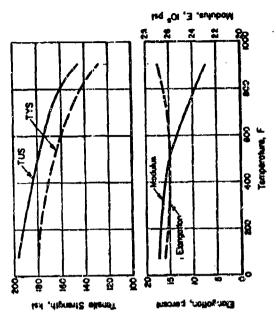
"太空" 南户9里396集 沙山

8.254 15./18.⁵

- under the subject recorraptors values her of tests. Talues are evertag of triplicacs teats conducted at lattelle usertace unions otherwise indistrate. Fatigue, ervep, and attract from excret generated using the trendits of a greatest masks 3
- Double-shear pia-type specimen; everage of 3 tests. 3
- U, umere'' Lile: MA, mat applicable.

Ξ

- bestage of 5 tests. Ĵ
- Three longitudinal and 3 transvence also-beed speciess were trited. Specimen size was 0.750-inch by 1.50 inches with a open of 6 inches, Arstage Equipment was 161.3 but 4fm. It the longitudinal direction and 121.9 but 4fm. It the longitudinal direction and 121.9 but 4fm. It the process direction. Sizes the size rate, 1.9 (Eq. 778.9), was presential both the specimen thickness and crack length in all bists, those values are any walt it, values by ordering ADTA establish. 3
- The regressing the algebraic ratio of stainer stress to maximum stress in one cycle; that is, it is $\mathcal{L}_{\rm SL}^{\rm FS}$ are represents the shocker-Peterber chosentical executions decoration ε
- Acceptomperotres throughout book tost. Attenuate Amerokee in 3-1/25 Medi. Û



FIGHR 1. SPECE OF TROUBLANDE ON THE TREEL PROPERTIES OF MY 941-416-0.XC FORGED BAR

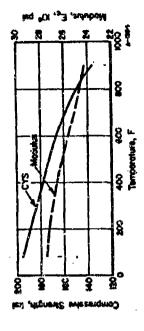
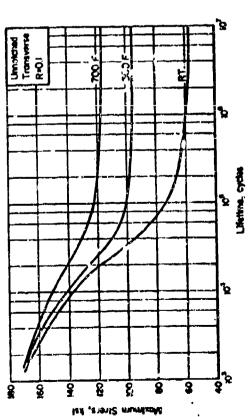
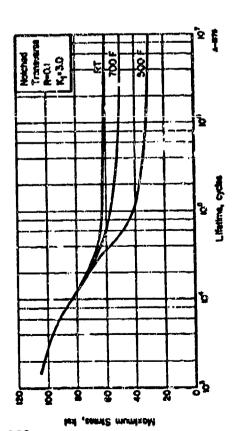


FIGURE 2. EFFECT OF TROPHANTORS OF THE CONFERENCE PROPERTIES OF NE WILL-ACA-0.200 PORCED MAN



FIGHE 3. ACIAL LOAD PATICIE REBALIS FOR GREGOTORID OF 951-405-0.100 FORCOD BAR



FIGHER 4. ANIAL LOAD PARTICLE RESULTS FOR MOTORIDE (K. - 5.0) HP 988.469-0.100 FORCED MIN

とは、大きなないのでは、これのでは、大きなないのでは、

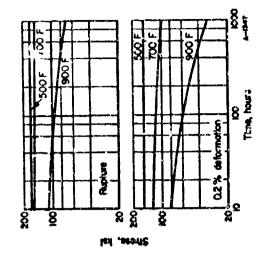


FIGURE 5. STRESS-WIFTURE AND FLASTIC DEFORMATION CONVERS FOR RP \$41.465-0, 20C FURGED BAX (TRANSVERSES)

PH 13-8 No Stainless Steel

Material Description

This allow is a marchestric precipitation hardenable staisless steel developed by the times Stail Carporation. It can be best treated to high strongth lawste and exhibits good dectility in the transverse direction. This transverse direction toughness is obtained by composition also seed to prevent of prevention of delite ferrite in the extractory, law earbon seatest to minimate grain boundary carbide precipitation, and double vecum molithm to avoid alloy segregation. The alloy reportedly has excellent resistance to etress ecreasion crecking in synthatic resonant and excellent resistance to werresion in a 5 percent out opens eartromement.

The natorial used in this evaluation was metained as a defact Selack m S feet forged but from Arms Beat 1882bil. The composition was as follows:

Percoak	0.03	0.00	12.62 8.34	2,14 1,03 Palence
Composition	Carbon Henganeta Paraberta	Sulfur Silican	Chronium .	Nolydomic Almina Tree

Preserting and Mare Treatles

Specimes were machined in the as-ressived Centillien A and then been treated at 1040 F for 6 bears 's Condition H 1000.

٠.

FR 13-0 No Stainless Steel Data (a)

Condition: MICOO Theimess: 4-inch forged bar

			Temperature,		i
Properties	E	907	905	700	8
Tracton					i 1
TIR Closed trackent), Inc.	142.7	2	169.0	157.7	128.3
(Presidente)	8	• =	16.3	147.3	127.0
(Jones Francisco)	187.3	· =	166.7	151.3	119.0
(183.3		163.7	169.7	118.0
lone (tradition)	13.3	=	12.5	(·/	21.2
persont to 2 to	13.8	• =	5 11	12.5	23.5
Comments and the second of the) :	3	5	2
TOTAL STREET		9 I			5 5
(tremoverse),	<u>,</u>	1 3		24.5	2.5
^	7.7	:		:: ::	21.5
6 (cremoverse), 10" per	3.	3	5.5	7.0	****
Compression					
;		1	:		•
(longittradina)	187.7	P :	156.3	150.7	134.3
or (transming), and		>	X	25.55	23.2
P	10.0	בן נ	25.7	Z	33.0
Bear			•	•	
SUS (longitudinel), hai	121.3	Þ	ê,	Þ	Þ
SSS (transverse), has	123.0	P	-	Þ	P
Descri (d)					
V-notch Charpy, ft. 1b.	3	•			
(transfirm)	15.	9	5 Þ	.	4 13
Practure Companies					
Therefore the Annual Control	3	=	þ	ŧ	þ
	:) (2)	, p	• p	, ,
Anial Patiges (transverse) (f)					
Denotabel, B = 0.1	315	900		191	
yeles.	15	3	· p	2	-
eyelos,	22	797	D	34.	Þ
, F.		!		;	٠
	2 5	3	D K	5 A	.
10 cycles, and	28	2 2	9 13	: 3	9 59

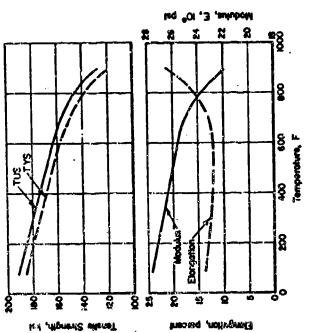
PR 13-8 No Stafnless Steel Data (continued)

				-	
Properties	ti i	903	\$00	200	8
Creep (transverse)					
0.21 plustic deformation, 100 hr, hai 0.21 plastic deformation, 1000 hr, hai	# #	6 6	833	95 8	22
Stress Rupture (transverse)					
hupture, 100 kr., ksi hupture, 1000 kr., ksi	11	c i q	E 29	83	53
Stress Corresion(E)					
SOL TYS, 1900 he sentimes	n erselu				
Coefficient of Thermal Expansion					
6.6 x 10° ta./ta./7 (80 to \$20 t)					

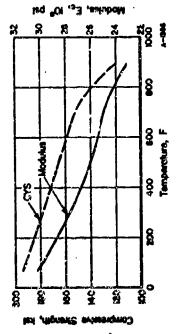
- (a) Values are emerge of tripificate tests conducted at Batbills under the subject contract unless otherwise indicated. Fatigue, ereop, and stress-repture values are from curves generated using the results of a greater number of tests.
- (b) Domble-wheer pin-type specimen; everage of 9 specimens.
- J, wasvailable; MA, mer applicable.

 $\widehat{\boldsymbol{\varepsilon}}$

- (d) Amerige of 6 toots.
- (a) Six longitudinal elom-band specimens were tested. Specimen else was 0.730-lach thick by 1.500 isolas wide with a span of 6 isolas. The everage R₀ obtained was 121.0 kel /Ix. Since the close satio, 1.5 (T₀/TTS)², was greater than Both the opacimen thickness and crack length in all tests, this R₀ value to make a valid K₁₀ value by existing ASIM criteria.
- (f) "h" represents the algebraic ratio of minam stress to maximum stress in one spain; within is, h, w Sim (Bunc. "h, represents the Bouler-Peterson transferral effects concentration Excess."
- (p) Been-temperature three-point best test. Alternate imercion in 3 1/23 Mell.

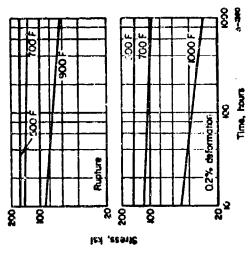


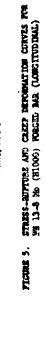
FIGUR 1. EFFECT OF TRUMBATURE ON THE TENSILE PROFESTIES OF PR 13-8 NO (RIGGO) PORCED BAR

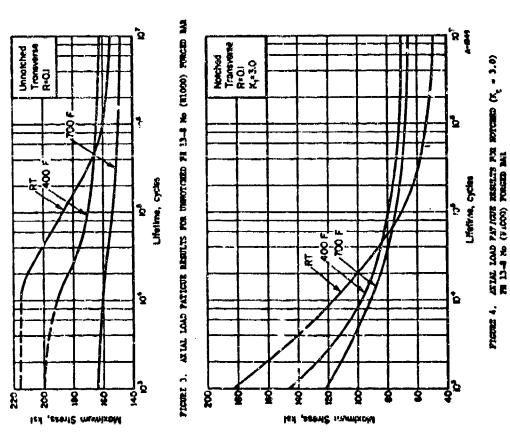


FIGUR 1, EFFECT OF TERTANDES OF THE CHERISTYLE FIGURE OF H. 13-8 No. (RIGOS) FORCED LAR

Denotity 0.279 1b./ts.*







7069-176 Aluminum Extrusions

Material Description

Alloy 7049 was developed by Enfact Aluminum and Chemical Corporation to have a strength level in the range of 7075-76 and 7079-76 coupled with a high resistance to attress corresion exciting. Initial development and production was in the form of forgings and hand forgings. Further development has been in plates and extrusions.

The material evaluated was a 4-lach x 4-lach sxirusion ampplied by Kaiser with the following composition:

Parcent	2.5	6.15	0.35 mex	0.0	Malases
Chemical Composition	Line Nagnesium	Chronium	Silicon	Ticanton	Mangacese Alvatava

Proceeding and Beat Treating

Specimes ware traited in the as-received -175 timper.

7049-T76 Aluminum Alloy Date (a)

では、10mmのでは、1

Thickness: 4-inch x 4-inch extrusion

		Tennerature	4 040	
Properties	2	250	ויים ו	<u>§</u>
Tension				
	•	7 77	9.87	17.8
(longitudinel)	76.2	5	6.9	16.4
(transverse), Kf1	7.92	(e)	5	P
Ľ		63.2	1.83	17.6
(locgicudinal)	67.4	56.4	43.8	16.1
(transverse), KS1	67.7	=	0	2
TTS (abort transverse), Fall	12.7	22.2	26.3	8.0
, percest in a	11.2	16.8	19.5	32.3
٠.	11.7	מ	Ω	Þ
(Short transverse), percent in	35.6	53.1	71.0	93.0
_	2.3	4.	51.3	4 7.3
AA (Eranswerse), percent	22.6	5	Þ	, 'a
(Josephandise), 10	10.7	9.3	8,2	• ·
Di Constant	6.6	6 .0	4.	: י
2	10.4	2	Þ	3
	;	. ;	•	9
(longitudinal)	78.8	 	7.75	17.7
ĭ	?		~	9
longitudinal), 10	10.5	10.2	7.6	7.7
Ke (transpared), to per				
Shear (b)				
;	7 37	=	F	Þ
SUE (longitudinal), tel	42.B	9	Þ	Þ
MIS WELLDE / F				
Impact (4)				
47 47 47 47 47 47				
Velocen Charpy, it. it.	9.8	þ	Þ	•
(transverse)	1.6	a	2	:
Practure Tourbease				
	,	1	1	
Ere (longitudinal), hel An.	3	b	Þ	>
G)				
Arial Patifue (transverse)				
Denotribed, R = 0.1		i	;	1
	21	٤:	S	p =
eyeles.	2 2	3,3	:3	9
lū, cycles, kāt	•	}	!	
				i

7049-T76 Aleminan Alley Data (continued)

いいこう こうまつ いんてい かん おんかれ はいしません このない はんない ないしょうしゅう

		Tasper sture, F	B.70. F	
Properties	1	Sã	23	8
Autal Fatigue (trensverse) (continued)				
Motched, K. = 3.0, R = 9.1				
10° cycles, had 10° cycles, had 10° cycles, had	\$ \$\$	37.	227	9 09
Greep (transverse)				•
0.22 plastic deformation, 100 hr, bai 0.25 plastic deformation, 1000 hr, bai	11	ងព	27	8 11
Stress Rupture (transverve)				
Aupture, 100 hr, kgi fupture, 1000 hr, kgi	44	32	##	3.5
Stress Corrosion(8)				
80% TWS, 2000 hr maximum	no errecht			•

Coefficient of Thermal Expension

12.9 x 10" ts./ts./? (30 to 212 F)

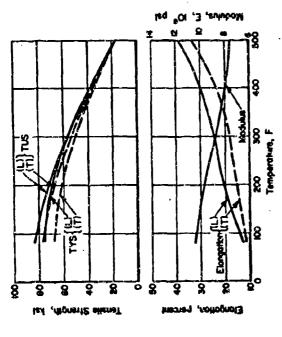
Denetity

0,099 1b./ta.

- Values are everage of triplicate tests conducted at Bathills under the subject costract unless otherwise indicated. Pathyre, eresp. sed ofress-repture values are free curves presented using the results of a gradum number of 1861s. 3
- Double-shear pla-type specimen; graveps of & teats. ŝ
- W. unevailable; MA, not appliable.

Û

- Awarage of 4L and 6T tasts. Ξ
- thick by 1.500 inches wide with a span of 6 inches. Specimes size was 0.730-lash thick by 1.500 inches wide with a span of 6 inches. The swenge R, obtained was \$4.1 baivin. Since the size ratio, 2.5 (Ro/TYS)², use greater that both the specimen thickness and creek length is all tests, this R_Q value is not a so walld L_C value by existing LSTS eriteria. 3
- "T" represents the algebrais ratio of minimus stress to norisons etrees in one cycle; that is, it a $\xi_{1,1}/\xi_{\rm max}$. " $\xi_{\rm c}$ " represents the Bookst-Petriron theoretical , stress concentration learns. $\boldsymbol{\varepsilon}$
- Respirangerators three-point bend test. Alternate immerator in 9 1/25 MaCl. 3



EFFECT OF TEMPORATINE OF THE TEMPORAL PROPERTIES OF 70% T/S EXTREMENTS FICURE 1.

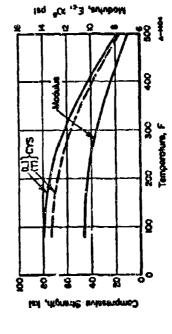
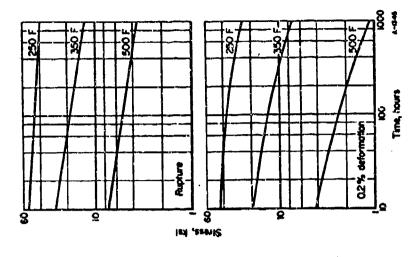
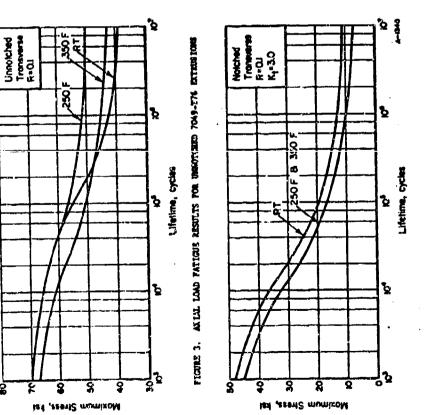


FIGURE 1. EFFECT OF TROPPLATURE OF THE CONTRESSIVE PROPERTIES OF 7045-176 EXHIBITION



FIGUR 5. STRESS-PUPTURE AND FLASTIC DEPOSATION CORVES FOR 7049-276 EXTRESTONS (TRANSVERE)



Figur 4. attal load partieur perturs for inficied ($r_{\rm c}$ = 5.0) 7089-176 actuarines

T1-541-25n-42r-680 Alloy

Naterial Description

initially, this alloy was dewloped by the Titonium Metals Corporation as an off-shoot of the Ti-Ail-Zan-Az-Zhonking temperature alloy. Studies had, shown that increasing the molyberum content beyond the 2 percent level resulted in an alloy having shown the molyberum content beyond the 2 percent level resulted creep resistance. During early development, investigation; were limited to the evaluation of the alloy as a heavy section forging alloy. Promising the temperature properties achieved in heat-trained sections up to 3 lackes suggest. Ithe alloy might also be useful as a sheet alloy since it should be air hardenable at

The material used in this evaluation was 0.075 fach sheet obtained iron INCA. It had the following composition:

Percent	5.98	4	5.86	0.057	0.10	6.00¢	Balance
C.mmteal . Composition	Alveinna	Zirconium	Holybdenum.	Iron	Oxygan	N. Lrogen	Titanium

Proceeding and Real Treating

Specimens were saichined in the et-received condition and heat-treated as follows:

- (1) 1650 F, 35 winutes, air crolad,
- (2) 1325 F, 15 minutes, air cooled,
- (3) 1100 F, 2 bours, air cooled.

Ti-6Al-25n-42r-6No Date(4)

Condition: Solution treated and aged Thickness: 0.080-inch sheet

L SI - AI	168.0 169.4 163.0	700	300	1000
fudinel), kai swerse), kai fudinel), kai swerse), kai swerse), percent in swerse), percent in tudinal), 10° pai swerse), 10° pai	168.0 169.4 160.0			
feudinel), kai averse), kai itudinal), kai strase), kai itudinal), percent in averse), percent in averse), 10° pai	168.0 169.4 160.0 163.0			
itudinal), kai Ludinal), kai Kudinal), percent in sverac), percent in ludinal), 10° pai sverac), 10° pai	169.4 160.0 163.0	149.3	140.7	105.3
itudicai), kai avers), kai avers), kai aversol, percent in aversol, percent in 2 itudical), 10° pai averso), 10° pai	160.0	150.0	142.0	106.6
averse), ksi kudital), percent in sverse), percent in 2 indinal), 10° psi averse), 10° psi	163.0	127.7	114.3	97.3
itudinal), percent in a swerse), percent in 2 itudinal), 10^6 pai swerse), 10^6 pai		130.7	117.0	98.9
averse), percent in 2 (rudinal), 10° pai averse), 10° pai		14.6	14.5	36.3
indinal, 10° pai		14.2	14.3	35.3
swerse), 10° p	•	16.3	15.1	12.8
Compression	17.2	15.6	14.6	12.8
CYS (lonestructing), 251	167.3	133.3	123.3	110.7
	170.6	138.0	126.7	112.7
(longitudinal)	19.4	17.9	16.3	13.9
10° pa	16.9	17.6	16.1	: :
Shear (b)				
HTS (lone(fud(ns)), kst	. 8.96	(e)	•	Þ
	1.96	ם	D	Þ
Fracture Toughnass (d)	;			
R. (crack direction LT), ket /In.	132	q	Þ	Ð
Arial Patigue (transverse) (a)				
	•		;	t
•	0 00	3	55	-
107 cycles, ket	3 201	<u> </u>	<u> </u>	: a
4			-	
101 Ched, K. w 3.C. K w 0.1	28	85	88	52
	35	3	2	5
geles	8	33	2	כי

Ti-6Al-2Sa-42r-6No Data (continued)

		Tempera	tan.	
Properties	Ħ	700	930	1100
Creep (transverse)				
0.2% plastic deformation, 100 hr, kei 0.2% plastic deformation, 1000 hr, kei	ន្តន	512	នដ	1:9
Strees Rupture (transverse)				
Supture, 100 hr, kel	≱ i	142	101	2,
Rupture, 1000 hr. ket	1	3	2	7.5
Stress Corrosion (f)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expension				

restrance of tograms Expension

5.5 x 10 to./in./7 (80 to 1000 T)

Denetize

3.165 1b./te.ª

(a) Values given are swerage of triflicate tests conducted at Battelle under the subject contract unless otherwise indicated. Values for fatigue, crosp, and atmas-rupture are from curves giverated using a greater number of tests.

(b) Single-shear sheat-type specimen; swarage of 3 teats.

U, unavailable; MA, rot applicable.

3

છ

Specimens were full sheet thickness x 18 inches x 16 inches with EDM flow in center.

 'R" represents the algebraic ratio of minimum etress to saxioms stress in one cycle; that is, R = Suin/Janx. "R," represents the Heuber-Peterson theoretical stress concentration factor.

(f) Bost-timpersties three-point band that. Alternate America is 3-1/25 McI.

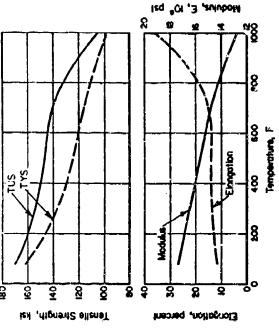
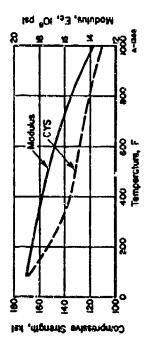
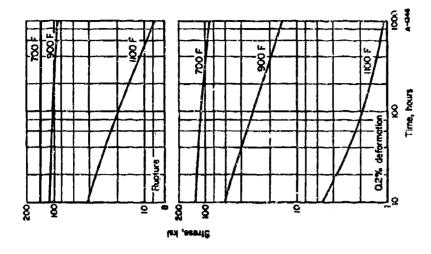


FIGURE 1. MPTECT OF TEMPERATURE ON THE FEMBLIE PROPERTIES OF TI-6A1-25m-4Zr-6HO SHEET



Fight 2. SPECT OF TRAPELATURE ON THE COMPRESSIVE PROPERTIES OF TE-641-28-427-640 SMEET

は、一般のないない。





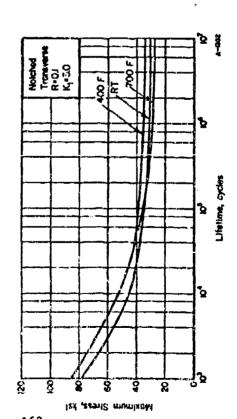


FIGURE 4. ALTAL LAND PATICUR RESPILES FOR MOTORID (T. = 3.0) TI-441-285-A27-AND REFER

PICCLE 3. AXIAL LOAT PATICUE RESULTS FOR URBUTCHED TI-GAI-256-427-696 STREE

Lifetime, cycles

Unnotched Transverse R=0.1

8 400 F

8

Noximum Stress, hal

The section of the contraction both the content for excellent restrained to a section of the contract of the c

The preside and fit . Andartha was 5,000 task plant from Bastle Professor Stouther West Statement and Colones.

Percent	សស្ត្រីកាសក្តីពីភូទិ សស្ត្រីកាសក្តីពីភូទិ ស្ត្រីកាសក្តីពីភូទិ
明初	Parties of the partie

The second secon

163

Increel 702 Alloy Data(a)

Condition: Aged Thickness .0,050-inch sheet

		Teatractione, ?	ure, F	
Properties	tz	630	(300)	ς.
Terafor			İ	
the Carletties of the	152.7	139.6	130.7	9
	151.0	'n	128.3	67.5
	8	25.7	3	63.6
	ł	. 98	85.3	65.3
	*	35.	×	9.3
	3	2		8.2
The state of the s	; ź	9.00	8	20.2
. =	ä	ž.	23.7	3).6
Compression				
ted (leasthanteen C and	\$	0	49.2	29
(remember)	101.0	10	51.0	2
Constitution!	4	35.0	7.31	17.12
ŧ.	*	33.3	4.5	2
			•	
Shear (8)				
Ma Hengfredingth, bet	116.2	S	۴	Þ
	115.7	-	<u> </u>	دا
Practure Touthbess				
Re. bol /la.	€	P	μ	12
Axial Patigue (transversa) (c)				
Denotribed, R = 0.1				
10 creiss, bot	Ç	43	Ŀ	t,
dele.	15	IJ	2	₽
10 cycles. hai	ឥ	¥	9	2
Botched, 7, a 3,0, 8 - 6,1				
celes.	æ.	*	۲,	to !
ele.	я,	<u>.</u>	e e	ti i
lo' cycles, ba	ķ	à	ñ	•

wante | 721 Julie: Bate (conclusion)

			Cancerstate. F	
	1.i	3.1	2710	15.00
Crass (Grassware)				
×	₩ (iii	\$	21,
with Mightie deformation, May in the	Q.	£	2	•
Steam before (transmitted)				
	# 9	ដូរូ	¥.	ដ
	Í	•	ń	1
Para Maria Para Para Para Para Para Para Para	s crabs	•		

C. Sell and M. Thomas Security of the Control of th

E

C. M. II Ab. A

(a) Makes are everupo of tripitemor beots seminatos at lattalla under the subject everunciam experience makes extravely fail with "Ritigan, errory, and stress-rubins walkes are free curve, generator velong the results of a greater wanter of

(3) Etaple-chest shorten or contains; n-ortho of 4 tests.

. of the same batter in the age (tradite.

(4) Specimens when that the third one of the tenth of the states with East flow or assert the man specime year, defend at the states we present than the translative states we present that the states we have a state of the states and the states are considered.

(e) "T" representative degradarile such all adalment strans to maximum ottobal in contract the such and the such and such activities the such activities and such activities and such activities and such activities and such activities and such activities and such activities and such activities and such activities and such activities and such activities are such activities and such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities and such activities are such activities are such activities and such activities are such activities are such activities and such activities are such activities are such activities and such activities are such acti

(t) has emperature from rate has seen, Alternate femerates in 3-1/22 fect.

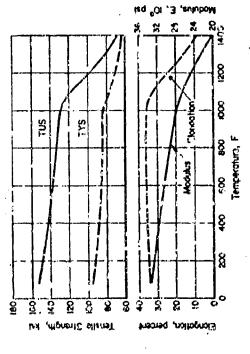


FIGURE 1. EFFECT OF TEMPERATURE ON THE TEMSILE PROFESTIES OF INCOMEL 762 SHEET (AGED)

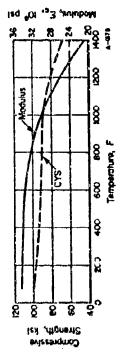
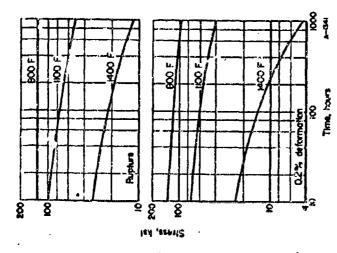


FIGURE 2. EFFECT OF TEATERANTIAS ON THE COURSESSIVE PROPERTIES OF DEGINEE 702 SHEET (ACCD)



かかま きまた 東北

日本の日本の人のないという のまかがる あれた 地方の大きないという

Umotched Tronsverse Partu

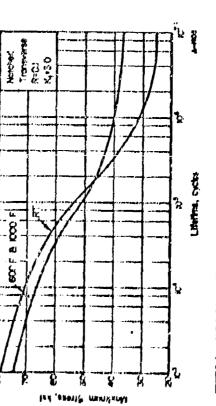


Figure 4. Will take rather results for reverse $(r_{\xi}+3.0)$ records, 700 axes: (400)

"在240人")是在1900年

בימים 3. ובינה נסבי הכונים אביניה זה מאומים הוטאים בינים (אנס)

Literature, cycles

194 HEATH MINNER W

Income 1706 Alloy

Meerial Secription

Incomed alloy 706 is a precipitation-hardenable, mickel-iroschromium alloy with characteristics similar to those of Incomed 713, except that 706 has improved anchimability. It has high strength at temperatures ranging from cryogenic to 1300 F. It also has good resistance to omidation and certosian ever a broad range of temperatures and environments.

Paintestion of the alloy is enhanced by its good formability and unlambility. Alloy 706 has excellent resistance to postweld strain-agning.

The manuful used in this evaluation was obtained as a 6-inchsquare freging from DECLMENT ENSONE. The composition was as follows:

Proent	0,03 0,12 36,37	(8 n 8 6 o 0	सर्व कर । इस्तु कर १ प्रकृतिक ।	
Chraftal .	College New Trees.	Saifer Silico Sensor	Oracina Alucina	Tringing Crisching Plus Fridal

Treated and feet treating

the 6-tack-equate uniterial was prace forging to a 2 toch w 6 inch forging to make syctomen blanks equies to obtain. After machining, epochena ware beds treated as follows:

- (1) 1800 T, 2 heurs, air mel.
- (C) 15% F, 3 keep, 4fr 600l,
- (7) 12357, Electri, furness caol to 1150 F, bold for 18 herrs, our cool.

Inconel 706 Alloy Data(a)

Condition: Solution treated and aged for optimum stress rupture attength
Thickness: 2-inch x 6-inch forged bar

			Temperature	ure. F	
Properties	RT	900	(i00	1000	1200
Tension					
TUS (longitudinal), ksi	177.7	•	156.3	151.7	138.3
TUS (transverse), kei	176.0	Þ	157.7	153.0	139.0
TYS (longitudines), hai	1.8.7	> :	125.7	119.7	2.6
Kal	140.0)	122.0	27.7	2.74
	22.2		7.7	10.01	
TCENT IN A	7 7 7	• •	7.07	2.5	9
KA (longicualnal), percent	9.4	> 2		5 6	
(transverse) perc	31.0	:		; r	9.0
. · ·	2.5	> =	7.7	21.5	8.00
•	3	•	•		
Compression					
ing (langlanding) has	140 7	E	126.7	123.3	120.0
(Lancacata)	149.0	בי	129.3	124.7	121.3
(longitudina)).	31.1	Þ	24.3	23.62	22.5
Ł	31.4	נט	24.2	24.9	22.2
(a)					
מוספוג					
SUS (lengitudinal), kei	11.2	p 2	() 10 10 10 10 10 10 10 10 10 10 10 10 10	= =	ta p
. /	77.0	>	2	•	,
Amount (d)		•			
Warmeteb Charpy, ft. 15.	*	=	E	P	, ,
(transverse)	7.92	>	Þ	D	9
Fracture Toughness					
I. (longitudinal), kei /In.	33	22	F) 13	D D	a e
Uncotched, R = 0.1	* A.	77.	=	132	Þ
		¥	. =	S	F
10 cycles, ket	3	8	. P	S	Þ
Morehad, N. = 3.0, R = 0.1	120	8	Þ	z	. يو
4	. 5	\$2	Þ	64	•
	*	Ä	Þ	ጸ	D

Iscoral The Alloy Data (continued)

		H.	Tamberature	fa _z	
Properties	£	£35	623	1350	300
George (trasperse)					
P. III PARTIE SPREEKING 100 NO 100 NO	2	tr.	133	表	ŕ
6.77 slosetic deformatica, 1000 kg, kat	4	į.	152	315	r
Street Purkers (transm 20)					
THE SECTION AND ADDRESS OF THE PARTY OF THE	ű	ţ,	3	143	33
Preters. 198 Mr. 125	ñ	מ	S	13	₽.
Stores Correction					
1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	e cracks	•			

(a) "taltas are everage of tribilente teste condected at Satiable under the subject ender alsen exhibits to finishing and stressing the version are true entered as greater number of

(b) Perblember plantype specimen; concept of A terror

(c) C, maruflable: W. met epplicable.

(4) amerage of & bears.

(a) Prive longitedinal and thrus transvarue slow-bond specimies were tested, specimen size were 0.750-inch thick by 1.500 inches side with a spec of 6 inches. The search of by National Marketon and allow the National direction and allow to National National Convertion. As The National Natio

(?) "W' impression the digetric rule of eludess either to madison altheo fe den epole; that is, i'm fuckly "I" impresent the deplotering theoretical exters. Committees the fetter fetters theoretical

(g) hem-lapprotest throm-point bed test. Assumer femining in 3-1/25 Medi.

のでは、100mm

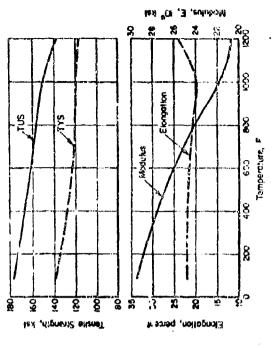
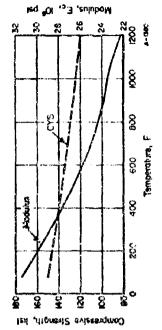


FIGURE 1. EFFICE OF TEMPORATINE OF THE TEMPILE PROFESTION OF INCOME. THE PORCED MAR (STRISSS-RUPTENE HEAT TREATMENT)

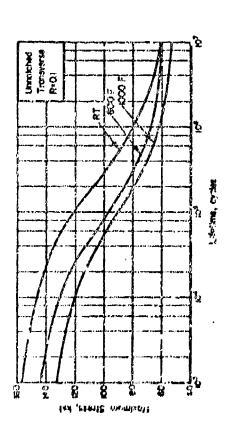


FIGUR 1. EFFECT OF EMPERATURE ON THE ORPHESSIVE FROPENTIES OF INCOME. 706 FORCE: AAR. (STRESS-KUPTOME HAAT TRANDER.)

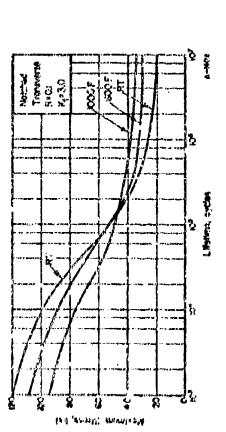
F/ 12 7.0

E C

Contractor of fartal Breading 1.8 x 10" to /le./7 (70 to 1500 7)



FIRMS 1. ALTHE LOSS BATTERS SERVICES FOR EXCROSION HELMES TAN FOREST BAT (FIRSTS) AND THE STATE SERVICES.



PICCE A. MULLIAN PRINCE BEEN TO BOTTON (R. + 3.0).
LITTER TO PRINCE AN COLES-MUTUR ENVIRONMENT

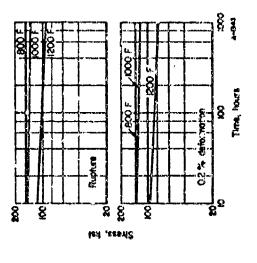


FIGURE 5. SCALUS-MUTURE AND ELACITO DEFORMATION CHAUSE FOR INCIDENCE 706 PORCED BAR (STRESS-REPTURE REAL TICALMENT) (TRANSVERSE)